METHOD OF MEASURING THE ECONOMIC IMPACT OF A RADIOLOGICAL DISPERSAL EVENT WITHIN AN URBAN ENVIRONMENT

THESIS

Antoine N. Munfakh, Captain, USAF

AFIT/GFA/ENV/10-M03

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government

AFIT/GFA/ENV/10-M03

METHOD OF MEASURING THE ECONOMIC IMPACT OF A RADIOLOGICAL DISPERSAL EVENT WITHIN AN URBAN ENVIRONMENT

THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science (Financial Analysis)

Antoine N. Munfakh, BS, MSM

Captain, USAF

March 2010

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AFIT/GFA/ENV/10-M03

METHOD OF MEASURING THE ECONOMIC IMPACT OF A RADIOLOGICAL DISPERSAL EVENT WITHIN AN URBAN ENVIRONMENT

Antoine N. Munfakh, BS, MSM
Captain, USAF

Approved:

//signed// — 15 March 2010
Lt Col David A. Smith (Chairman) — Date

//signed// — 15 March 2010
Dr. Leonard J. Kloft (Member) — Date
Wright State University

//signed// — 15 March 2010
Lt Col Eric J. Unger (Member) — Date

AFIT/GFA/ENV/10-M03

Abstract

A radiological dispersal event (RDE) is the result of a Radiological Dispersal Device (RDD) or a dirty bomb. An RDD is a low-yield conventional bomb surrounded by radiological material (RM) such as Cesium-137 or Cobalt-60. Upon detonation, the blast of the conventional explosive is designed to spread the RM over a wide area. The RM will then be inhaled or ingested by people, or otherwise absorbed into the environment.

An RDD is an affordable, feasible, and economically devastating option for terrorist groups. Possible RM could be stolen or acquired cheaply from the millions of radioactive sources used worldwide in industry, for medical purposes and in academic applications.

The purpose of this research is to develop a generalized methodology that can be used to assess economic impacts resulting from an RDE, occurring in any location and across any industry. Currently there is no universal approach for measuring the costs or economic impacts on businesses, nor a common framework for estimating an economic impact of a radiological event, leading to inaccurate and unverified estimates. The objective of this research is to aid in the RDE response effort by providing government planners, officials, and key stakeholders with an economic assessment tool which can be used to quantify the economic impacts arising from a RDE, thereby facilitating the strategic decision making process.

As part of the methodology, this thesis used an I-O Model to evaluate the economic impacts on a proposed study site representing a mid-sized US city. The methodology used in this study can be expanded and applied to other regions or cities.

In applying the methodology to a case study location, this research identified and quantified the district within the city with the largest impact, the Central Business District. In addition, the study showed that the direct, indirect, and induced costs remained consistent independent of the sector at approximately 60%, 15%, and 25% respectively. The significance of such a finding is that previous attempts to quantify the impact only measured the direct effects and thus did not capture approximately 40% of the total costs. The maximal total 1-year impact for an RDE in the CBD is approximately $1.4 billion covering 860 firms in 270 distinct industries. In addition, approximately 18,000 workers will be unemployed immediately following the attack, with an additional 113,000 people affected by the shift in the local economy as a result of indirect and induced effects.

This work is dedicated to my beautiful and extremely supportive wife, my loving parents for giving me the drive to succeed, and to my mentor Vinny, without whom I would not have had this opportunity.

Acknowledgements

It is with sincere appreciation that I would like to thank the following people for their patience, time, and expertise throughout the course of this thesis effort:

- Lt Col David A. Smith, Department of Systems and Engineering Management, Air Force Institute of Technology, Wright-Patterson AFB, OH
- Dr. Leonard J. Kloft, Department of Economics, Wright-State University, Dayton OH
- Lt Col Eric J. Unger, Department of Systems and Engineering Management, Air Force Institute of Technology, Wright-Patterson AFB, OH
- Bureau of Labor Statistics Midwest Information Office, Chicago IL
- Mr. Mark Loewenstein, Bureau of Labor Statistics, Washington D.C.
- Maj. Marc Ferguson, Air Force Research Laboratory, 711th Human Performance Wing, Wright-Patterson AFB, OH
- Dr. Edward White, Department of Mathematics and Statistics, Air Force Institute of Technology, Wright-Patterson AFB, OH

Antoine N. Munfakh

Table of Contents

List of Figures and Equations

Page

List of Tables

METHOD OF MEASURING THE ECONOMIC IMPACT OF A RADIOLOGICAL DISPERSAL EVENT WITHIN AN URBAN ENVIRONMENT

I. Introduction

A radiological dispersal event (RDE) is the result of a Radiological Dispersal Device (RDD) or a dirty bomb. Although in the same category as a nuclear, biological, or chemical weapon, an RDD does not generate its power from splitting or fusing atoms as a nuclear bomb does. This study used the standard convention that an RDD is a low-yield conventional bomb surrounded by radiological material (RM) such as Cesium-137 (Cs-137) or Cobalt-60 (Co-60). Upon detonation, the blast of the conventional explosive is designed to spread the RM over a wide area. The RM can then be inhaled or ingested by people, or otherwise absorbed into the environment.

An RDD is an affordable, feasible, and economically devastating option for terrorist groups. An RDD is affordable and feasible because possible RM could be stolen or acquired cheaply from the millions of radioactive sources used worldwide in industry, for medical purposes and in academic applications- mainly research.(Frost, 2005) The U.S. Nuclear Regulatory Commission has estimated that within the United States, approximately one RM source is lost, abandoned or stolen every day of the year. (Ferguson, Kazi, & Perera, 2003) And, in a report to congress in 2008, it was predicted that an RDD is likely to be used sometime before 2013. (Graham & Talent, 2008)

An RDE is ideally suited to the case of economic warfare in that it has the potential to cause major local economic disruptions immediately and extend them over a period of time.

The strategic placement of the device within an urban center will determine the economic impact of the RDE. There are at least three economic centers within any city that are possible targets for an RDE: the industrial center(s), the retail area(s), and the business district(s). This research uses Dayton, Ohio as its model of a mid-size urban center. Within Dayton, one industrial center is the General Motors manufacturing plant in Moraine (Figure 1-1). There are a number of retail areas within Dayton, but the Fairfield Mall (Figure 1-2) was selected for this research based upon its size (it is a major retail center) and proximity to key secondary establishments: a military installation, an airfield, and a major university, all of which will be impacted negatively based on their proximity to the fallout area. An urban environment may have numerous business districts however, the Central Business District (CBD),

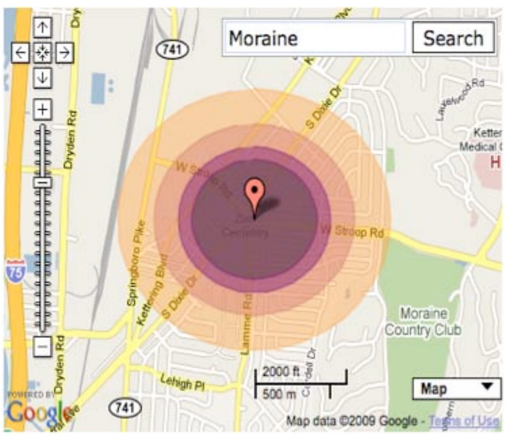

Figure 1-1: RDE Fallout Area Moraine GM Plant – Industrial Center (Google, Inc)

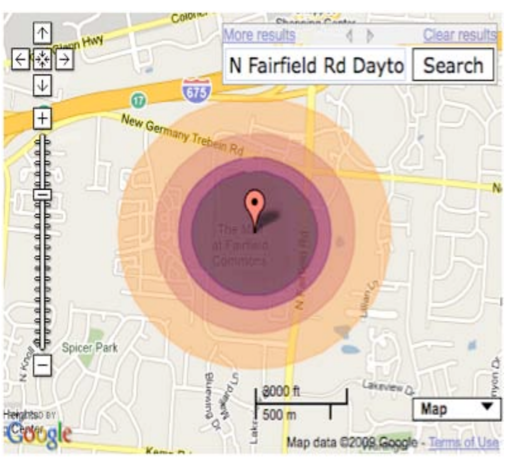

Figure 1-2: RDE Fallout Area Fairfield Mall -- Retail Center (Google, Inc)

located in downtown Dayton, is the primary business district for the Dayton Metropolitan Statistical Area (MSA).

The CBD contains banks, corporate offices, and service industries such as law firms and accounting agencies. In general a CBD is considered the heart of any MSA. (Figure 1-3)

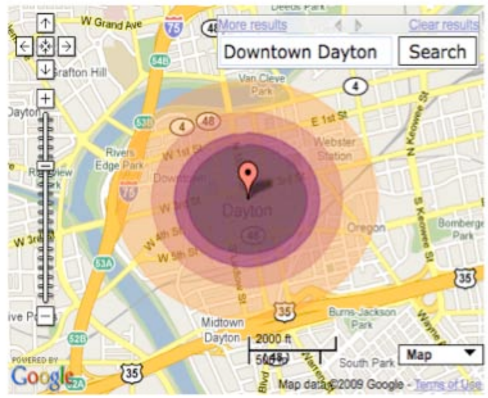

Figure 1-3: RDE Fallout Area Central Business District -- Commercial Center (Google, Inc)

According to the Center for American Progress, a team of nuclear researchers concluded that terrorists are "all but certain" to set off a radiological weapon in the United States (Grotto, 2005). Incidents over the last several years have supported these concerns. In May 2003, the U.S. arrested an American, Jose Padilla, in Chicago’s O’Hare airport for his involvement with Al Qaeda in planning a radiological attack on the United States. In January 2003, British officials found documents in the Afghan city of Herat indicating that Al Qaeda had successfully built a small radiological explosive device and that they possessed training manuals on how to employ it. (Gardner, 2003)

The RDE threat is real, and an actual radiological attack could occur on U.S. soil within our lifetime. Government officials are already aware of the threat and, in a document distributed to Congress, highlighted an RDE attack as one of a number of viable threats that the government must be prepared to confront. (US Department of Homeland Security, 2006)

The general public often misunderstands the nature of the RDE threat because of a lack of credible information. Due to this misunderstanding, there is no shared appreciation of the problem or how best to address it. The reality is that the threat of a dirty bomb attack by terrorists is a credible one, though the economic impact of an RDE was not properly measured in prior studies.

Therefore, this research seeks to measure the unknown: What is the economic impact of an RDE on the retail, industrial and commercial regions of a mid-sized city?

Background and Research Purpose

Research on this topic was conducted previously, the most recent study was in 2009. That study began a first step in developing an approach to measuring the direct, indirect, and induced economic effects of an RDE on retail businesses. (LeBrun, 2009) The direct effect is the known or predicted change in the local economy that is to be studied. The indirect effects are the business-to-business transactions required to satisfy the direct effect. Finally, the induced effect is derived from local spending on goods and services by people working to satisfy the direct and indirect effects. Prior to LeBrun's research in 2009, all attempts to quantify the effects of an RDE only studied one portion of the economic impact, the direct effect.

Although the prior research was able to identify the three components of the economic impact, the study was unable to obtain actual revenue data for the study site. As such, the revenue was approximated based on square footage of the retail stores. Using these approximations, it was calculated that the effect of an RDE within the Fairfield Mall retail sector was approximately $1.2 billion. In contrast to LeBrun's work this study uses actual revenue data from 2007 for the Dayton MSA, obtained from the Bureau of Labor Statistics (BLS) to more accurately model the economic impacts of an RDE for the three distinct economic sectors. In addition, this research ultimately developed a methodology to calculate the maximal point of economic impact among the three sectors, thereby facilitating local and regional strategic decision-making. This study used an input-output model (I-O Model) to evaluate the direct, indirect, and induced costs of an RDE.

Results

In using the I-O Model, it was discovered that in the wake of an RDE, the most impacted sector is the CBD. (Figure 1-4) In addition, the direct, indirect, and induced costs remained consistent independent of the sector at approximately 60%, 15%, and 25% respectively throughout the entirety of the MSA. The maximal total 1-year impact for an RDE in the CBD is approximately $1.4 billion (BY2007) covering 860 firms in 270 distinct industries. In addition, approximately 18,000 workers may be unemployed immediately following the attack, with an additional 113,000 people affected with either lost wages or unemployment throughout the MSA as a result of indirect and induced effects

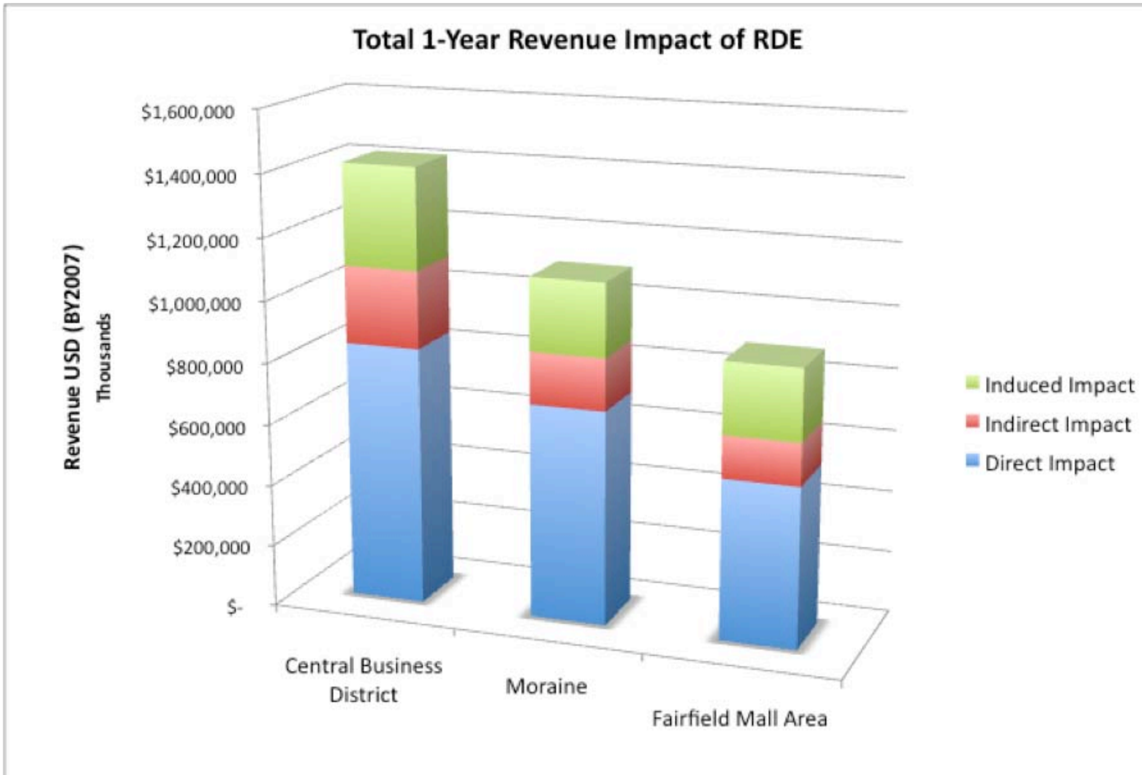

Figure 1-4: Total 1-Year Revenue Impact of RDE

II. Literature Review

In March 2006, the US Department of Homeland Security (DHS) developed the National Planning Scenarios, a strategic planning document outlining several key threats and expected outcomes of such events in terms of lives lost, costs, and impact to national infrastructure. The document describes the US government's plans for various disasters or attacks:

> *The Federal interagency community has developed 15 all-hazards planning scenarios (the National Planning Scenarios or Scenarios) for use in national, Federal, State, and local homeland security preparedness activities. The Scenarios are planning tools and are representative of the range of potential terrorist attacks and natural disasters and the related impacts that face our nation. The objective was to develop a minimum number of credible scenarios in order to establish the range of response requirements to facilitate preparedness planning.* (US Department of Homeland Security, 2006)

Scenario 11 of this document considers a Radiological Attack using a Radiological Dispersal Device. The DHS estimated that 180 fatalities, 270 injuries and 20,000 instances of contaminations would occur, resulting in 10,000 people evacuated to shelters with an additional 25,000 people ordered to shelter-in-place. In addition, hundreds of thousands voluntarily self-evacuate from urban areas in anticipation of future attacks. The direct effect of an RDE was previously unknown but the best estimates analysts derive was simply, "up to billions of dollars." (US Department of Homeland Security, 2006, pp. 11-1) The methodology used in the NPS 11 to generate this estimate is not evident and does not appear to be based on any repeatable method. Rather, it seems as if this estimate was derived from the aggregation of expert opinion and is a best guess approximation. This estimate is unacceptable when considering the feasibility of such an attack; it is simply executed, its resources are easily available, and its impact widespread - physically, psychologically, and economically.

Perception and Economic Impact of the RDE Threat

In order to effectively model the economic impact of a RDE, it is necessary to highlight previous research in the field, examine prior documentation of the economic fallout from radiological events within mid-sized cities. Fortunately, there have not been any intentional radiological events within mid-sized cities and the number of unintentional events has been limited. In order to compensate for a lack of real world events on which to base my analysis, a review of unintentional radiological events as well as intentional conventional terrorist attacks was used as a suitable proxy to determine the extent and range of a hypothetical RDE impact on the economy.

Before one can begin to measure the effects of a RDE, one must understand what it is. The Council on Foreign Relations classifies RDDs as weapons of mass destruction. (Council on Foreign Relations, 2006) This term is applied because although such a device would probably not result in a large number of deaths nor widespread physical destruction, the device itself would create panic and disrupt the normal functioning of society. Although in the same category as a nuclear, biological, or chemical weapon, it is not a device that generates its power from splitting or fusing atoms as a nuclear bomb would. In reality, a radiological dispersal device is a low-yield conventional device surrounded by radiological material such as Cesium-137 (Cs-137) or Cobalt-60 (Co-60). Upon detonation, the blast of the conventional explosive spreads the radiological material over a wide area, which can then be inhaled or ingested by people. Those who received a sufficient dose of this radiological material may exhibit signs of radiation sickness such as nausea, vomiting, diarrhea, weakness, and even death, although the number of casualties is expected to be small. Rather, the real impact of such an event is the isolation of sections of the city for businesses. Sections of a city that are contaminated will be isolated and businesses located within those sections will not be able to generate revenue.

To date, there have been no successful incidents of radiological terrorism using dirty bombs. There have been several notable radiological accidents and attempted attacks on nuclear power plants. But there has not yet been a successful malicious attack resulting in extensive destruction. Therefore, the physical (on humans and on surrounding infrastructure), financial, environmental, psychological, and political effects of a radiological terrorist attack cannot be fully grasped. Experience with past radiological incidents, computer simulations, and terrorist attacks, were used to estimate the physical and environmental impact based on known effects of radiation, conventional bomb blasts, and other factors. This study developed a repeatable method to model the economic impact of a RDD within a mid-sized city and generated estimates at three key locations.

"The economic impact of a radiological attack has the potential to be as devastating, if not more, than the physical attack itself," according to the Nuclear Threat Initiative (2004), a private think-tank group. LeBrun's study (2009) of RDEs within mid-sized cities seems to support this statement. For one dirty bomb detonated within a retail sector the total cost of lost revenue and employment was calculated at nearly $1.2 billion (BY03). This study, however, did not consider decontamination or reconstruction costs, but examined the loss of revenue and employment. The aftermath of a RDE could include treating and decontaminating victims, evacuating and relocating people from the affected area, decontaminating both the interior and exterior, or completely demolishing affected buildings, safely discarding the radioactive debris, decontaminating the emergency vehicles used in the decontamination process, and many other activities. These efforts alone could cost billions of dollars. (Monterey Institute of International Studies Center for Nonproliferation Studies, 2004)

During the decontamination process, buildings in the affected area may not be functional. Residents would likely have to be relocated. Businesses may have to do the same or simply halt their activities until completion of the decontamination. Depending on the nature of the business conducted inside those buildings, the regional and national economy could be negatively impacted. U.S. Federal guidelines, issued by the EPA in 2009, recommended reducing the cancer risk from remaining radiation to low levels by abandoning the contaminated area or demolishing buildings, but this decision rests largely with leaders in the local community who would take into consideration the costs of clean up, the value of the contaminated property, and the health and disruptive effects on people's lives. (Monterey Institute of International Studies Center for Nonproliferation Studies, 2004) For an affected area in the middle of a mid-size city, such as Dayton, OH, abandonment could cause thousands of people to lose their homes, jobs, and schools. Buses and other transportation systems might require re-routing. Even if the area can be decontaminated to the levels required by Federal guidelines, the psychological perception of increased radioactivity in the area could have its own economic impact.

One of the most significant consequences of a radiological attack may be the resulting psychological anxiety. Because most people are unfamiliar with radiological terrorism, they may mistake a dirty bomb attack for a nuclear weapon attack. The general public's fear of radiation could likely cause mass panic after a release of radiation from an attack on a nuclear facility or the detonation of a radiological device, further exacerbating the economic impact. Additionally, hospitals may be overrun with people complaining of and possibly showing symptoms of radiation sickness, even if they were nowhere near the attack site or the radioactive fallout, as was the case in Brazil. In this example, 250 people were actually exposed to a radioactive substance, but once it became public, 135,000 requested screening for exposure and 5000 people showed psychosomatic symptoms of nausea and skin rashes mimicking symptoms of actual exposure but were not ever exposed. These symptoms were caused strictly by the anxiety of potential exposure.(Warwick, 2001) Such false reporting would create congestion in the healthcare system in the local area, delaying treatment to those who may be affected. Some people may experience increased levels of stress and anxiety. Perceptions of continuing contamination might lead residents to move to other areas causing a significant drop in home values and real estate, further impacting the economy. Potential tourists might be dissuaded from visiting the affected area or city. Some may become fearful of more terrorist attacks and refrain from visiting any highly trafficked or densely populated areas, adding to the negative economic impact of the attack. A resulting decrease in the area's real estate prices, tourism, and commercial transactions could have long-term negative effects on the area's economy. These effects are beyond the scope of this study, but should be evaluated in further studies.

To quantify these negative effects, it is necessary to valuate the individual costs of such an event. After an RDE attack, there will be economic loss due to forfeited revenue from local businesses affecting not just their consumers, but their suppliers as well. These effects can be measured using an I-O Model to estimate the total losses in business and employment based on the losses of individual business. The Input-Output Model is a detailed accounting system of inter-industry activities within a local economy and it is based on the economic theory that the output of one industry is an input to other industries. (Minnesota IMPLAN Group, 2009) The Impact Analysis for Planning (IMPLAN) software uses this theory to develop a Social Accounting System to describe transactions that occur between producers and intermediate and final consumers. (Natural Resources Conservation Service, 2009) Because Social Accounting Systems examine all the aspects of a local economy, they provide a more complete and accurate "snapshot" of the economy and its spending patterns. (McIntosh, 1997, p. 15) In addition, IMPLAN is able to derive a multiplier model mathematically using the I-O Model and Social Accounting System.

The Multiplier Model is what gives IMPLAN its predictive ability in economic impact analysis. (Natural Resources Conservation Service, 2009) Once there is a clear picture of the economy through the Social Accounting and Multipliers, its behavior can be predicted for a defined event: if Company X spent 20% of its earnings on widgets in 2006, then received an additional $1,000,000 of income from a new project in 2007, the widget industry could expect to make approximately $200,000 more that year. If 5% of the widget producer's industry is spent on steel, the steel industry could expect $10,000 more; and so on. However, at each of these steps, each company will source some products out of the region of the economy of study. These are the losses that occur and eventually drive the cycle to zero. The total increase in economic activity from a $1 million project is the economic impact of the project; $1,000,000 spent became at least $1,210,000 of economic activity giving Company X a multiplier of 1.21 - every dollar spent on Company X creates 1.21 dollars of economic activity. (Minnesota IMPLAN Group, 2009)

Clean up, demolition, and reconstruction costs are beyond the scope of this research and cannot be quantified by an input-output model; however, the costs are estimated to be in the billions of dollars. Reconstruction and clean up after the terrorist attack of September 11 on the World Trade Center cost approximately $16 billion according to the Executive Director of the Port Authority of New York and New Jersey, Chris Ward. With 1.5 million tons of debris removed, at a cost of $16 billion, the cost is approximately $10,700 per ton of debris removed after a terrorist attack. This is, of course, simply a rough estimate and may vary widely based on geographic region, but will be another cost in addition to the loss of employment and revenue.

In order to effectively model the economic impact of an RDE, it is necessary to examine the economic impact of previous similar events. Since detailed studies of economic impacts resulting from radiological terrorism are scarce, comparable studies such as the adverse affects of natural and manmade disasters on an area's economy, as well as conventional terrorist attacks will be examined in order to provide a framework from which we can measure the accuracy of the final model developed from IMPLAN.

Benefits of Economic Analysis

Conducting economic analysis after terrorist attacks or localized disasters provides emergency managers an ability to gauge the severity of the damage and the funding required to be able to provide assistance at all levels (City, State, Federal). The Federal Emergency Management Agency is the largest and most visible branch of emergency managers and is at the highest level. Because of the impact and RDE would have both economically and psychologically, it is expected that the President will declare a disaster for affected regions. The declaration of a disaster or emergency by the president enables special funding as well as special rules for sourcing the recovery and reconstruction efforts. In the immediate aftermath of a disaster, cost estimates must be conducted to determine the extent of damage and are required to be accurate to 10% within 90 days after the declaration of disaster in accordance with federal guidelines. (United States General Accountability Office (GAO), 2008) However, in order to make funds available during the fiscal year, estimated costs are submitted to be included in the congressional appropriations process for the next FY budget. FEMA uses the 5-year annual average level of obligations for past disasters, adjusted for inflation, as its estimate of the total cost of disasters anticipated to occur during the current fiscal year. To estimate when during the year the disasters will occur, FEMA simply allows the 5-year annual average to decline at a constant rate (8 percent) each month during the fiscal year. "Using this approach, FEMA estimates that disasters costing about $500 million will occur in August and September 2000. However, these months represent the height of the hurricane season, and over the last 5 years, the average cost for disasters to FEMA has been twice this amount," (United States General Accountability Office, 2000) and as such, they are regularly underestimating the cost of disaster events, forcing the agency to request additional funds from Congress.

Case Studies:

Conventional Terrorist Attack: Sept. 11, 2001 World Trade Center Attack

After September 11, 2001, it was predicted that New York City and the nation would continue to suffer the economic ramifications of the terrorist attack for years to come. (William C. Thompson, 2002) Because of this, a team of economists and budget analysts from the office of the Comptroller studied the financial impact of the September 11 attacks on the economy of New York City. The estimated economic loss was calculated by "one-time wealth loss and a continuing loss in jobs and Gross City Product (GCP)." (William C. Thompson, 2002) Wealth includes both fixed capital (buildings, infrastructure) and human capital (labor market). The Comptroller estimated the impact of the World Trade Center attacks on the city's wealth as $30.5 billion, of which $21.8 billion is the cost to replace lost buildings, infrastructure and tenant assets and $8.7 billion is an estimate of the present value of the future earnings of those who died. (William C. Thompson, 2002) Real GCP losses by calendar year were $27.3 billion for the period from September 2001 through September 2002. (William C. Thompson, 2002)

Despite these tragic losses, the loss of lives and property on 9/11 was not large enough to have had a measurable effect on the productive capacity of the United States even though it had a very significant localized effect on New York City. In a national sense, the Gross Domestic Product (GDP) was low in the first half of 2001 (Makinen, 2002), data published in October showed that GDP had contracted during the third quarter and positive growth resumed in the fourth quarter. This would suggest that any effects from 9/11 on demand were short lived at the national level. This finding validates the decision to limit the scope of this research to remain at the local level, simply because,

> *"…for [a terrorist attack] to affect the economy it would have had to have affected the price of an important input, such as energy, or had an adverse effect on aggregate demand via such mechanisms as consumer and business confidence, a financial panic or liquidity crisis, or an international run on the dollar."* (Makinen, 2002)

It could be argued that a dirty bomb will affect aggregate demand via psychological impact on the consumer. However, such an outcome is unlikely and ultimately the impact will not be large enough to halt the growth of the national economy. Although the GDP may show a slight change in the growth rate, as was the case after 9/11, the affects at the national level will most likely be very brief and minor. The more likely outcome will be a compounding of the economic impact at the local level.

Accidental Manmade RDE: Goiania, Brazil

In 1987, one of the most serious radiological accidents in history occurred in Goiania, Brazil (International Atomic Energy Agency, September 1988). The consequences of this event provide a baseline for possible economic impacts that could be experienced from a terrorist attack using radiological material. In the case of Goiania, the RDE was a result of improper handling of abandoned medial equipment, and was composed of Cs-137. The Cs-137 was acquired from an abandoned radiation-therapy unit after the doctor relocated his practice. According to nuclear weapons expert John Pike (2002), Cs-137 would be the most likely material used in the assembly of a dirty bomb, because it is very easy to obtain and can be found in "low-level waste from medical or research labs, or welding shops and construction sites" (Boyle, 2002). In the specific case of Goiania, two people entered the premises and, not knowing what the unit was, removed the source assembly, took it home, and dismantled it, subsequently rupturing the capsule that housed the radioactive material. Environmental contamination resulted due to the unintentional dispersal of the material, resulting in 249 people externally irradiated, 129 people internally contaminated, and 4 deaths (International Atomic Energy Agency, September 1988)

As a result of the Goiania accident the region suffered a huge economic loss as well as a lasting psychological impact on the local population. The fear of exposure to radiation, irradiation, and incurable damage to health caused more than 200 residents to evacuate from the area. (International Atomic Energy Agency, September 1988) Additionally, the inhabitants were discriminated against because of the misunderstood nature of radiation. Sales of cattle, cereals and agricultural produce, as well as cloth and cotton products (the main economic products of the area) fell by 25% in the period after the accident. (International Atomic Energy Agency, September 1988, p. 115) Ultimately, the cost of six months worth of intensive cleanup, which required seven houses and several buildings to be demolished, amounted to $27.2 million. However, the indirect costs due to negative economic repercussions were estimated to be as high as hundreds of millions of dollars. The GCP for Goiania decreased by 20% and did not recover to pre-RDE levels for an additional five years. (Sohier & Hardeman, 2006, p. 175)

Psychological Impacts of Accidental RDE: Three Mile Island

In 1979, a partial core meltdown of a pressurized water reactor at the Three Mile Island Nuclear Generating Station became the most significant accident in the history of the American commercial nuclear power generating industry. It resulted in the release of 13 million curies of radioactive noble gases (primarily xenon) and 13-17 curies of Iodine-131 into the atmosphere. The accident began with failures in the non-nuclear secondary system, followed by a stuck-open pilot-operated relief valve in the primary system, which allowed large amounts of reactor coolant to escape into the environment. As a result of this disaster there were short-term and long-term economic losses despite relatively harmless nature of the noble gases and the minor amount of Iodine-131. No significant level of radiation was ever noted outside of the TMI facility. (Walker, 2004)

Short-term costs of the Three Mile Island (TMI) accident were largely a result of the evacuation of the surrounding area. 144,000 people within a 15-mile radius of TMI were displaced at a cost of $18 million (Flynn, 1979). In addition, there were other health costs related to TMI. Although the level of radiation was considered too low to cause any increase in cancer rates, public heath was affected. There was an increase in the number of workdays lost due to fear of radiation poisoning, as well as an increase in the number of people presenting to the hospitals for treatment. Anti-anxiety medication was prescribed more frequently to help relieve the stress of exposure. Some patients even began experiencing the signs and symptoms of radiation sickness, although they were not exposed. (Flynn, 1979, p. 38) Additionally, businesses were affected in the short-term simply because of the loss of production during the first week after the incident. Manufacturing plants self reported revenue losses of approximately $7.7 million while non-manufacturing plants lost $74.2 million. These losses would have been much higher if not for $180 million in government aid for clean-up and economic development.

The long-term economic impact was not as severe and is harder to quantify. Evidence from previous studies conducted by Gamble and Downing in 1981 and Evans in 1981 show that sales of single family homes within a 25-mile radius of TMI before and after the accident remained consistent with no measurable affects either positive or negative. The long-term costs of cleaning and maintaining the power plant while not in operation is approximately $1 billion, in addition to purchasing power from out-of-state companies at higher rates. All these costs, however, are still miniscule when examined from a macro-perspective on the US as a whole. RDE events are significant to the local area and will devastate a region, but will be isolated to the local level.

Accidental Manmade RDE: Chernobyl

The Chernobyl nuclear accident imposed huge costs on the former Soviet Union and three successor countries; Belarus, Ukraine and the Russian Federation. Although these three countries bore a significant portion of the impact, the spread of radiation across the borders of the USSR forced other countries such as Norway, Finland, Sweden, Denmark and the Netherlands to sustain economic losses as well. Chernobyl is, on a grand scale, what can happen with a terrorist-detonated RDE. Although a portable RDE will not be as big nor as devastating as Chernobyl, an attack on a nuclear power plant to incite an intentional meltdown could be as large as Chernobyl. In this regard, the events and costs from Chernobyl can provide us an upper limit in our cost estimates and economic impact models. The costs related to Chernobyl vary in scope, but the 30-year cost was estimated by the IAEA in a report to the United Nations at $235 billion for Belarus alone. (International Atomic Energy Agency, 2006, p. 33) Some of the direct costs are related to clean-up, healthcare, and radiation monitoring for the area. However, because the events of Chernobyl required removal of agricultural land and forests from use and closure of nearby agricultural and industrial facilities, there is also an indirect cost and lost opportunity to use the land and facilities. (International Atomic Energy Agency, 2006, p. 32) 330,000 people within a thirty-kilometer radius were evacuated and resettled, most of whom were farmers. Once removed from the land they were unable to work or get different jobs because of a social stigma associated with the event. Even as late as 2003, wages tended to be lower and unemployment higher within the regions affected by Chernobyl. Additionally, restrictions on agricultural production crippled the market for foodstuffs and other products from the affected area. As a result, agriculture revenues have declined, production was reduced drastically, and some facilities have shutdown. In Belarus, where some of the best arable land was removed from production, the whole economy has struggled. There seems to be no end in sight as continued environmental monitoring and government aid is required in order to protect and sustain the populace. These costs ranged from 6% to 22% of the GDP, (International Atomic Energy Agency, 2006, p. 32) and continue to have a stranglehold in developing future growth for Belarus, Ukraine and Russia.

RDE Study: Port of Los Angeles

In 2005 a study was conducted on the economic impacts associated with a RDE in the twin ports of Los Angeles and Long Beach, California. This study addressed the effects of a terrorist-induced RDE. (Gordon, Moore, Richardson, & Pan, 1 May 2005, p. 25) Gordon and his economics team at the Center for Risk and Economic Analysis of Terrorism Events (CREATE) identified major United States ports as attractive targets for terrorists, for three reasons: First, they can be accessed by land, air, and sea; second, they are difficult to secure; third, RDEs can be shipped in and detonated upon arrival at the port – no need for extraneous personnel as the device is being transported by the freight company. Furthermore, major ports enable terrorists to achieve one of their most important goals - maximum economic damage. Ports need to utilize several forms of transportation, including roads, railways, and waterways to ensure the volume of goods shipped to the US are moved expeditiously. The closure of a port due to a dirty bomb attack for even a few days could have a severe impact on the supply chain of hundreds or even thousands of companies.(Gordon, Moore, Richardson, & Pan, 1 May 2005, p. 11)

Rosoff and von Winterfeldt (2007) conducted follow-on research by providing a risk and economic analysis of dirty bomb attacks on the ports. The economic analysis conducted measured vehicular traffic flow from the major roads and rail lines that bisect through the harbor as a proxy to measure revenue lost. This was the first attempt to quantify economic impact at a smaller level than the GCP. They determined a range of economic impacts due to a shutdown of the harbors based upon the duration of the shutdown. For a short-term (15-day) shutdown, the impact was relatively minor at only $300 million, because most ships would wait out the closure and businesses could be resupplied in the short term from local vendors. Medium and long-term shutdowns due to the contamination resulted in significant losses ($63 and $252 billion, respectively), including decontamination costs, as well as business and property losses. The potential for an extended shutdown of operations (or the amount of time when the economy will be unable to function) is stated by Rosoff to be one of the major concerns of an RDE threat to the L.A. - Long Beach ports, simply because the longer the ports are not operating, the greater the effects will be on the local, state, and perhaps national economies. (Rosoff & Winterfeldt, 2007, p. 542) Rosoff validates the notion of how businesses within the port area could possibly suffer economic losses due to the stigma of having their companies located within a contamination zone. Depending on the amount of commerce that takes place within the area, the costs of business disruptions could be large, certainly in the billions of dollars, but only if one assumes the majority of businesses relocate outside of the region or cease to exist.(Rosoff & Winterfeldt, 2007, p. 543) The psychological aspect of contamination could have the ability to cause patrons and residents to leave the area and not return, thus causing the economic effects of the RDE.

Summary

The effect of an RDE is a massive impact into a local economy. Previous research has given various ranges of the impact based on size, location, and severity of contamination. However, all prior studies either used the change in the GCP or proxies to estimate the economic impact. The limitation of the GCP is that it is reactionary. The earliest indications of actual lost revenue will be in quarterly GCP reports and will require multiple reports to show and isolate trends and changes. These products are a good way to identify actual revenue lost but are unable to provide estimates if needed before the report is published. Other studies used proxies such as vehicular traffic or revenue per square foot to estimate revenue loss for an area. This method of using proxies is able to produce estimates sooner than the GCP reports, these estimates are only as robust as the proxy used in an estimate, which may not reflect the actual revenue loss that could occur.

III. Methodology

Modeling the economic impact of an RDE required a number of critical assumptions, generalized systems of organization, a systematic approach to calculating the results and in the end, I had a number of limitations that the model was unable to capture.

Assumptions

There were a number of assumptions made in the course of this research ranging from the size of the area affected by the RDE to the RM used in the construction of the RDD. Additionally, assumptions were made regarding factors related to economies of scale within the city and location factors related to each site. These assumptions allowed for the creation of an effective modeling system to measure and capture the effects of an RDE within an urban environment. Using MSA data and adjusting the number of firms and types of industries within the impact zone this methodology can be applied to any metropolitan area within the US for any size RDE.

Size of Impact

In accordance with National Planning Scenario 11, 97% of the fallout of 2,300 curries of Cs-137 RDE will fall within a 36-block or 1-mile (diameter) area. (US Department of Homeland Security, 2006) In following the NPS example, my assumptions are:

- As a result of the explosions, 90% of the 2,300-curies Cs-137 source is aerosolized and carried by winds, with radioactive particles ranging in size from 1 to 150 microns. The remaining fallout creates debris and contaminates surrounding structures.
- All businesses within the 1-mile area are closed for an extended duration while radioactive contamination is remediated.
- There is no precipitation. There are light, variable winds of 3 to 8 mph. The temperature is 65°F.
    - This assumption is critical, as weather factors will change the shape and size of the contamination area within the study site. Because of an assumption of good weather with little wind, the distribution of contamination will be circular.

This research is predicated on the assumption that NPS Scenario 11 is accurate in its assumptions regarding the size of the area affected and the resulting procedures to cleanup and decontaminate the surrounding area.

Type of Radiological Material Used

Generally, the most hazardous radioactive materials are found in nuclear power plants and sites where nuclear weapons are made and security is high. As a result, obtaining materials from these areas would be extremely difficult, although not impossible. Radioactive material could be obtained on the black market from North Korea, Iran or even Pakistan, all of which have well-financed nuclear development programs. However, according to John Pike, Nuclear Weapons Expert and Director of Global Security, it would be more likely that radioactive materials for use in an RDD would be obtained from low-level waste such as medical or research labs (i.e. diagnostic procedures, cancer treatments), or welding shops and construction sites (i.e. industrial radiography). (Boyle, 2002)

Therefore, for the purposes of the current study, it is assumed that the simulated RDD will contain Cs-137, since this radioactive isotope is one of two (Cobalt-60 being the other) elements most commonly used within industrial and commercial sources. Experts also believe that this material will be the most likely substance used in the event of a possible RDE. (Boyle, 2002)

Economies of Scale

Economies of scale are the cost advantages that a business obtains due to expansion resulting in a producer's average cost per unit to fall as scale is increased. Any size firm expanding its scale of operation may utilize economies of scale. The most common advantages a firm may experience by increasing its scale are: purchasing (bulk-buying of materials through long-term contracts), managerial (increasing the specialization of managers), financial (obtaining lower-interest charges when borrowing from banks and having access to a greater range of financial instruments), and marketing (spreading the cost of advertising over a greater range of output in media markets).

This research generated two working models under two different assumptions. The first model was a baseline model, with no economies of scale. Small firms and large firms produce the same revenue per employee for a given industry. In the second model, a more dynamic model, economies of scale were considered but are assumed to be linear in order to simplify the analysis; however other geometric distributions can be considered if needed. The slope of the revenue line is constant and the area under the curve provides total revenue. This allowed for an accounting of the effects of economies of scale while maintaining a degree of flexibility within the model. Actual economies of scale vary widely from linear to exponential depending on the individual firm. (Clark, 1984) Although not perfect in its model of actual economies of scale, the linear approximation is sufficient in its ability to reflect the revenue lost to an RDE as a generalized economy of scale applicable to the MSA as a whole and demonstrate the need to consider the effects economies of scale have on the total effect. The accuracy lost is not substantial enough to warrant the added complication of more complex economies of scale.

Urban Economics and Location Factors

Urban economics is defined as the study of allocation of scarce resources across an urban space. As such, it involves using the tools of economics to analyze their relation to the urban environment and additionally, how the urban environment affects the decision of producers and consumers with regards to location selection, production and consumption.

The three sites selected within Dayton are unique in certain regards. The CBD in particular accounts for a larger proportional share of revenue than other business districts located outside of the city center. As such, the CBD will have a larger proportion of revenue when compared with other business districts (Blair & Carroll, 2009) and this should be accounted for when attempting to generalize this methodology to other areas or other regions.

Upon examination of the MSA-level data, assuming the industries found in the CBD are consistent throughout all business districts within Dayton, the CBD holds approximately 15% of all business district type firms in relation to the MSA and conducts nearly 12.5% of the revenue when compared to the MSA in those specific industries; however, of the three major business areas within the MSA, the revenue of the CBD is 50% above average. The Fairfield Mall area contained 8% of firms when compared with other mall type industries while accounting for 17.84% of the total revenue. When compared with the average revenue from the five major malls within the MSA, Fairfield was nearly 30% above the average. The Moraine GM plant area contains 3% of all firms in relation to the MSA when compared to those specific industries, but conducts 18.4% of the revenue for industrial-type sectors when compared to the industrial area industries found throughout the MSA. Moraine additionally conducts 67% more revenue then the average when compared with the other four other industrial sites within the MSA. However, because of the selection of the three largest locations of their respective type within the MSA, this provides decision makers the worst case scenario and can justify the exclusion of location factors from this study. Ultimately, as a limitation of the model, a key assumption made is that all firms generate equal revenue indifferent to the location of the firm within the MSA.

Data Distribution

In order to effectively analyze the results of the model, the distributions of the effects (direct, indirect, and induced) were analyzed. The results appear to follow a beta distribution. Although each industry within each of the districts examined may have other revenue distributions, each of the effects for the districts must be analyzed in order to develop a proper range of confidence of the effect.

Systems of Organization & Analysis

In order to effectively model a complex urban environment, a system for organizing and analyzing the different industries is required. For this research, the North American Industrial Classification System (NAICS) was used to organize the MSA data into industry specific groups, while the Impact Analysis for Planning (IMPLAN) software is used to develop the analysis of the dataset.

North American Industry Classification System (NAICS)

Prior to creating the I-O Model, all businesses within the MSA must first be industry coded. This is an important step because IMPLAN measures impacts on individual industries, not individual businesses. Industry coding may be accomplished through the use of NAICS. NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.

IMPLAN I-O Modeling

The Impact Analysis for Planning (IMPLAN) software application was used to generate multipliers in order to measure the direct, indirect and induced effects of the RDE on the economy's output and employment. Multipliers are a numeric way of describing the direct, indirect, and induced impact of a change. An employment multiplier of 1.8 would suggest that for every 10 employees hired in the given industry, 18 total jobs (in all sectors) would be added to the given economic region. (McIntosh, 1997) The IMPLAN I-O Model is suitable for analyzing this research in that it provides the user with region-specific economic data of each branch of economic activity within an area's financial system. The program computes multipliers (direct, indirect and induced) for any given industry in any given location, based on regional industrial composition (Social Accounting Matrix) and geographic area. A Social Accounting Matrix (SAM) represents flows of all economic transactions that take place within an economy (regional or national). It is, at the core, a matrix representation of the measured economic activity for a given country, but can be extended to include non-national accounting flows, and created for whole regions or areas. By simulating a "shock" to any industry or multiple industries of an economy (i.e. an RDE), the user can see how that impact ripples throughout the user-specified local economy.

Recent economic data collection improvements made by the Bureau of Economic Analysis, U.S. Census Department, and other governmental and private organizations have made the I-O Model one of the most important, popular and accurate methods for measuring the economic impacts on a region due to exogenous or endogenous policy and economic changes. (Cheng, Stough, & Kocornik-Mina, 2006) I-O Models have been successfully applied in other economic disruption estimations, such as electric power outages (Rose, Oladosu, & Liao, 1997), hypothetical earthquakes (Okuyama, Hewings, Kim, Boyce, Ham, & Jungyul, 1999) and hurricanes (Lamb, 1995).

Procedures and Methods

This research used IMPLAN to model the economic impact of a simulated RDE in an urban center. The economic impact was estimated by the calculated loss of employment and revenue using IMPLAN's internal I-O Model. National Planning Scenario 11 determines the size of the affected area for fallout to be within 1-mile of the detonation. (US Department of Homeland Security, 2006) Businesses affected within the proposed study sites were identified by their NAICS code. Employment and annual revenue was collected for each industry identified and located within the study sites. Results of the I-O Model included direct, indirect, and induced economic effects in terms of revenue and employment lost. Economic impacts for each of the three proposed study sites was measured over a 1-year period.

This methodology can be generalized to other cities and counties by recreating the steps outlined below or can even be roughly approximated by the use of the results applied to the location quotients for Dayton compared to location quotients for other cities. The end result of such a study will be a demonstration of the magnitude and severity of a radiological device to any economic center as well as to show which areas (commercial, retail, or industrial) within a city may be more likely to be targeted. Targeting of specific sites will be analyzed for the 1-year total impact beginning at different periods throughout the year by applying industry specific seasonal factors. The seasonal factors will show how effects on the economy can change over the course of a year, and as a result, which months will lead to the most immediate impact of an RDE for a given site.

Proposed Study Site Selection

The first step of the methodology is locating study sites distinct from each other but within the same MSA to be able to differentiate results within a city. Additionally, in order to select a viable location, it is important to understand why terrorists commit the acts that they do. According to Club de Madrid, terrorist acts are typically motivated by psychological, political, religious, cultural, or economic reasons. (Club de Madrid, 2005) Terrorists also prefer to conduct their destructive operations in high-visibility; public areas where they can be witnessed by as many people as possible (Center for Non Proliferation Studies, 2004)

Since this study looks to assess the economic impacts of a terrorist act (RDE), the three proposed study sites used within this research were based on their primary industry, with each site addressing a specific revenue generating sector: commercial, industrial, and retail. These sites will be used to show not only a comparison between the different industries and district compositions of the effects of an RDE but to highlight as a case study how such an analysis can be completed for any district of any MSA.

For the commercial sector, the Dayton Central Business District (CBD) was selected. The site of the CBD contains banks, corporate offices, and service industries such as law firms insurance and brokerage companies, and accounting agencies and is generally considered the heart of any MSA. The Industrial sector is represented by the Moraine GM plant, which until 2008 was operating at full capacity, producing a number of different GM cars, trucks and SUVs. Although the plant has since been closed, the revenue and employment data used is from 2007 and matches with IMPLAN input-output model whose social matrix is based on 2007 data; this is not a limiting factor as all results will be in BY 2007 dollars for comparison and modeling purposes. The final site of study is a retail sector. Although there are a number of different retail centers in and around Dayton, the Fairfield Mall was selected because of its size, proximity to several major roads and government facilities (Wright-Patterson AFB)

Create a Map Overlay

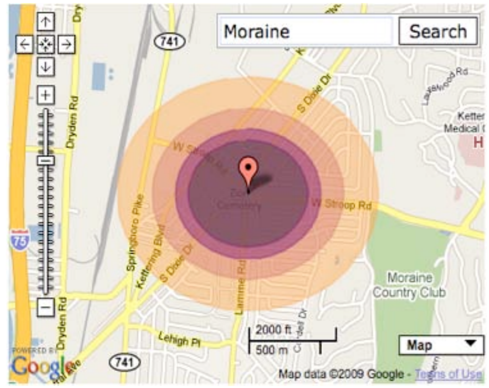

Figure 3-1: RDE Fallout Area Moraine GM Plant – Industrial Center

The next step was to determine what commerce was affected by the RDE. Since the National Planning Scenarios indicate a majority (90%) of the fallout to be contained within 1-mile, a series of concentric circles is superimposed onto an aerial photomap of the impacted area, in order to provide a clearer picture as to which business areas within the economy were directly affected with possible contamination. The image was placed over the mapping application based on the locations selected. In order to assist with the identification of local area business, the selected areas were forwarded to the Bureau of Labor Statistics (BLS), which has compiled data by zip code. This data was further refined to the 1-mile area by the BLS upon request.

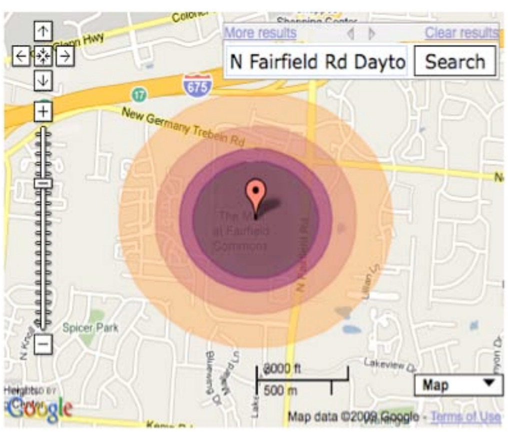

Figure 3-2: RDE Fallout Area Fairfield Mall -- Retail Center

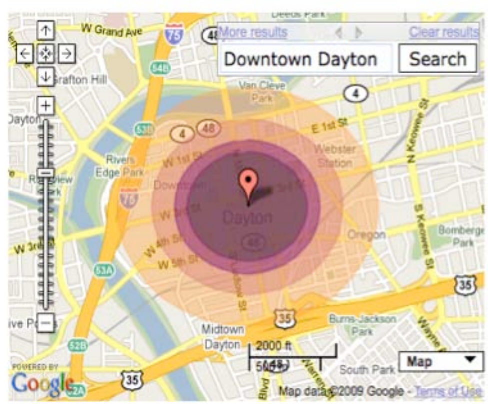

Figure 3-3: RDE Fallout Area Central Business District -- Commercial Center

Data Collection

Once the affected businesses were identified, the next step was to identify the economic parameters necessary to calculate the economic impacts. For the purposes of this research, annual revenues and employment data were used. This information was collected by the BLS and available in a number of sources including:

- US Census Bureau 2007 Economic Census (US Census Bureau, 2010)
- BLS County Business Patterns (2007): Employment and Business Data (United States Department of Labor, 2010)
- American Fact Finder: Economic Patterns (US Census Bureau, 2010)

The BLS further refined the data to the 6-level NAICS identifier; data collected from online sources will be masked at such a high level of fidelity and was unmasked upon special request. Revenue data was only able to be collected at the MSA level and would need to be scaled down in order to estimate revenue generated within each of the three study sites.

Scaling Annual Revenue

The annual revenue data necessary to conduct the economic impact analysis was easily collected for the MSA. The MSA revenue and employment data was collected from 2007 economic census, however, the BLS assisted in unmasking data points that were not divulged to prevent individual firm identification. Once all the data points were unmasked, it was necessary to scale down the revenue data for each industry to reflect each of the three regions actual composition of industries.

Table 3-1: Sample Region Data - Employment by Industry

Industry Code	Industry Code Description	Total Firms	Number of Employees in Firm Size Categories									
			1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	1000+	SUM
220000	**Utilities**	**2**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
221310	Water supply & irrigation systems	1	2	0	0	0	0	0	0	0	0	2
221320	Sewage treatment facilities	1	3	0	0	0	0	0	0	0	0	3
230000	**Construction**	**23**	**24**	**23**	**85**	**74**	**0**	**0**	**0**	**0**	**0**	**0**
236115	New single-family general contractors	1	2	0	0	0	0	0	0	0	0	2
236220	Commercial building construction	6	7	8	0	33	0	0	0	0	0	48
237310	Highway, street, and bridge construction	1	0	7	0	0	0	0	0	0	0	7
238140	Masonry contractors	1	2	0	0	0	0	0	0	0	0	2
238160	Roofing contractors	1	0	8	0	0	0	0	0	0	0	8
238210	Electrical contractors	5	5	0	41	0	0	0	0	0	0	46
238220	Plumbing and HVAC contractors	2	5	0	0	0	0	0	0	0	0	5
238290	Other building equipment contractors	4	1	0	34	41	0	0	0	0	0	76
238310	Drywall and insulation contractors	1	0	0	10	0	0	0	0	0	0	10
238910	Site preparation contractors	1	2	0	0	0	0	0	0	0	0	2
310000	**Manufacturing**	**30**	**30**	**24**	**104**	**195**	**0**	**140**	**0**	**0**	**0**	**0**
315239	Women's & girls' cut & sew other outerwear m	1	0	5	0	0	0	0	0	0	0	5
321920	Wood container & pallet mfg	1	0	0	18	0	0	0	0	0	0	18
323110	Commercial lithographic printing	5	3	14	37	0	0	0	0	0	0	54
323114	Quick printing	3	5	5	0	0	0	0	0	0	0	10
323115	Digital printing	1	4	0	0	0	0	0	0	0	0	4

Although the BLS provided actual data on employment for the three regions based on composition and categorized by firm size (Table 3-1), they were unable to provide actual revenue numbers. In order to effectively use IMPLAN, the revenue data from the MSA level needed to be scaled down to the regional level. This scaling was conducted in two distinct functions: a constant economy of scale function and a linear economy of scale function. The constant economy of scale function provides a simple baseline, under the erroneous assumption that an employee in a given industry produces the same revenue as any other employee in that industry. Under the linear economy of scale function, employees in a larger firms produce more revenue than their counterparts in smaller firms.

In order to build the constant economy of scale baseline a constant weight system was developed based on ratio of employees in each size category to total employees

Table 3-2: Sample Annual Revenue -- MSA Level

IMPLAN Code	Industry code description	Annual Revenue Per Firm by Employees Weight of Total ($1,000) 1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	1000+
	Mining	**576.37**	**1605.59**	**5475.48**	**1111.56**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
20	Crude Petroleum and Natural Gas Extraction	64.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Crushed and Broken Limestone Mining and Quarrying	103.44	586.14	2482.49	930.93	0.00	0.00	0.00	0.00	0.00
26	Construction Sand and Gravel Mining	365.24	887.00	3182.76	0.00	0.00	0.00	0.00	0.00	0.00
27	All Other Nonmetallic Mineral Mining	0.00	167.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Utilities	**14420.80**	**10094.56**	**20910.15**	**169444.36**	**187470.35**	**284089.68**	**275437.21**	**0.00**	**0.00**
31	Fossil Fuel Electric Power Generation	586.99	0.00	2739.29	8609.19	34241.11	77091.41	74743.45	0.00	0.00
31	Electric Power Distribution	28908.47	0.00	0.00	0.00	614305.04	0.00	0.00	0.00	0.00
32	Natural Gas Distribution	1738.53	6084.87	0.00	83015.03	0.00	0.00	0.00	0.00	0.00
33	Water Supply and Irrigation Systems	4259.28	0.00	21296.41	0.00	0.00	0.00	0.00	0.00	0.00
33	Sewage Treatment Facilities	4248.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Construction	**96547.81**	**79343.19**	**92702.99**	**126723.86**	**70410.77**	**94178.78**	**50487.59**	**0.00**	**0.00**
37	New Single-Family Housing Construction (except Operative Builders)	2678.52	3392.80	2035.68	0.00	0.00	0.00	0.00	0.00	0.00
39	New Multifamily Housing Construction (except Operative Builders)	2360.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	New Housing Operative Builders	1930.24	2629.12	2429.44	1730.56	3760.64	0.00	0.00	0.00	0.00
39	Residential Remodelers	11009.73	4259.24	2651.98	2705.55	2839.49	0.00	0.00	0.00	0.00
35	Industrial Building Construction	576.27	0.00	777.96	0.00	4927.08	12706.69	0.00	0.00	0.00
34	Commercial and Institutional Building Construction	6373.19	5203.43	13109.42	13593.46	5001.75	7623.63	17627.12	0.00	0.00

within a given industry. This weight allowed distribution of the annual revenue based on the given weights revealing approximate annual revenue based on categorized firm sizes for each industry (Table 3-2). Once the revenue was scaled to the size categories at the MSA level, a second weight could be developed based on the specific site to be tested. This scale used the ratio of employees in a given category at the site-specific level to the number of employees for the same industry and size category at the MSA level. The totals for each industry were collected in order to develop total annual revenues per industry, which could then be compatible with the IMPLAN software to calculate total impact and output lost in terms of both revenue and employees.

The simple constant economy of scale model does not accurately reflect the complexities within an economic system. Economies of scale are the production and cost advantages that a business obtains due to expansion and is a long run concept referring to reductions in unit cost as the scale of the facility increases. These production and cost advantages may permit employees to be more productive or reduce the overall cost and thus produce higher revenue per employee ratio when compared with smaller firms in the same industry. In order to model economies of scale, the weight system was modified to reflect a linear growth. Although the total revenue per industry remained unchanged, the distribution of the revenue to the different firm categories was no longer a simple weight. In order to build the model, the following equations were used:

Equation 3-1

$$\text{Total Revenue} = \int_{1}^{n} mx(dx)$$

n = number of employees in industry

Equation 3-2

$$\text{Weight} = \frac{\int_{a}^{b} mx(dx)}{\int_{1}^{n} mx(dx)}$$

a = 1 + number of employees in ALL previous size categories
b = number of employees in size category + number of employees in ALL previous size categories
n = number of employees in industry

Understanding that the total revenue is the area under a curve, it is possible to build a weight by taking the integral of a given portion of a curve and compare that to the sum of the integrals of different portions of the curve (since the curve may not be continuous) to generate a weighting system which will allow larger firms to receive a larger proportion of the revenue when compared to smaller firms.

Sector Coding

Once all businesses are classified by NAICS, IMPLAN further consolidates these codes into sectors (Table 3-3). IMPLAN has the ability to examine 509 different

Table 3-3: Sample IMPLAN Sector Scheme

IMPLAN Sector	IMPLAN Description	2007 NAICS
212	Photographic and photocopying equipment manufacturing	333315
308	Ophthalmic goods manufacturing	339115
321	Retail - Furniture and home furnishings	442XXX
396	Medical and diagnostic labs and outpatient and other ambulatory care services	6214XX, 6215XX, 6219XX
400	Individual and family services	6241XX
16	Logging	1133XX
91	Apparel accessories and other apparel manufacturing	3159XX

sectors of an economy. Sectors 1 through 494 are made up of NAICS coded industries. In order to use the IMPLAN multipliers to determine direct, indirect and induced effects, revenues need to be aggregated by sector. Then these revenue totals may be calculated against the multipliers.

Sensitivity Analysis

In order to produce a range of impact estimates, the economy of scale was varied between 1% and 100% in order to simulate the potential range of the impact based on variations in a difficult-to-measure theoretical economic principle. Because the economy of scale is estimated as linear and broadly applied to all industries, there will be an inherent inaccuracy. However, the variation of the data, which is critical in order to provide civic leaders with a good estimate of the range of damage, will emerge from such an analysis. Since economies of scale are not easily measured, sensitivity analysis can show how the variation in the economies of scale will quantitatively change the effects of an RDE within a region and provide a distribution from which to calculate a confidence interval or range of the expected effect of an RDE.

Seasonality Analysis

Simply stating that an RDE provides a simple annual impact does not provide the full understanding of the impact of an RDE. In fact, the timing of the RDE is a critical factor in maximizing the impact of the effects. In order to model seasonality, monthly industry revenue data from 2007 was used to build monthly percentages which could be applied to the revenue based on each region. This provides monthly revenue data for each industry. Compiling the monthly revenue data provides a total effect by month. In order to determine which month will result in the largest economic impact, one must isolated the seasonal effects from the total effects. This process required differencing the cumulative seasonal effects from the cumulative non-seasonal impact. By computing the area under the curve of the isolated seasonal effects it is possible to determine which month(s) would result in the largest added impact to a region above the non-seasonal effects.

Limitations

Although a powerful tool, IMPLAN is limited as an economic modeling tool only. It is unable to account for costs resulting from cleanup, remediation efforts, or the impact to residential property. These costs are expected to be a substantial burden valued at "hundreds of millions of dollars per site." (US Department of Homeland Security, 2006) In addition, the economy is a dynamic entity while IMPLAN is using static historical data to build its modeling system and thus may not be a good predictor for future forecasts, however, because of the continuous updates to both the data gathered by BLS and the I-O Model from IMPLAN these drawbacks can be minimized by conducting such an analysis on a recurring basis with the new datasets and models. The benefit of using historical data to generate estimates is that although the point estimate may be inaccurate, the calculated variance will ensure with some confidence that the actual value will fall within the range of predicted values.

Additionally, a linear representation of economies of scale is not perfect in modeling actual economies of scale. However, a linear approximation is sufficient in its ability to reflect the revenue distribution between small firms and large firms proportionally within an economy. This distribution will allow for a more accurate model, while the accuracy lost by not applying exponential economies of scale is not substantial enough to warrant the added complication of more complex modeling.

Although different sites of similar type will have different revenues based on both actual revenue generated and factors associated with the location of the site within the MSA, the added complexity and possible inability to model the location factors would have made the model too unwieldy to accurately estimate the economic impact of an RDE. As such, by selecting the largest (by overall revenue generated) representative site for commercial, industrial, and retail districts within a city, the analysis will produce the worst-case scenario for each type of location (i.e., all business districts, all retail centers, or all industrial areas) within the MSA.

Summary

Modeling the economic impact of an RDE required a number of critical assumptions, from the size of the RDE to the type of RDD to modeling economies of scale and location factors. In addition, by using established and recognized systems of organization (NAICS) and analysis (IMPLAN) and following a systematic approach to calculating the results, these results are repeatable and the method can be generalized to other MSAs outside of Dayton. Although faced with a number of limitations that the model was unable to capture, I believe the efficacy of the model in predicting the impact cost of an RDE within any mid-sized MSA to be sound.

IV. Results and Analysis

The economic impact resulting from a simulated RDE attack within a mid-sized city is dependent on where the RDE occurs within the city. The direct, indirect, and induced estimates vary based on the location and type of sectors affected. There is a distinct difference in the impact of an RDE based on the location of the detonation; the CBD, a retail center (Fairfield Mall) or an industrial area (Moraine GM plant) all produce markedly different results. In addition, the month of detonation plays a critical role in maximizing economic impact, which unsurprisingly is dependent on the location of the RDE.

Initial Results

The initial results of this analysis showed that over a 1-year period, while holding economies of scale constant, the economic impact of an RDE is as follows:

Table 4-1: Mean Revenue Impact due to RDE

	Mean Revenue Impact ($ Millions)		
	Central Business District	Moraine	Fairfield Mall
Direct Effect	$840.1	696.5	$522.1
Indirect Effect	$250.8	$168.4	$137.8
Induced Effect	$327.2	$236.4	$231.1
Total Effect	$1,418.0	$1,101.3	$891.0

Table 4-2: Employment Impact Due to RDE

	Employment Impact		
	Central Business District	Moraine	Fairfield Mall
Direct Effect	18,137	20,248	12,156
Indirect Effect	46,020	43,737	28,143
Induced Effect	66,837	55,167	46,562
Total Effect	130,994	119,152	86,861

Sensitivity Analysis

By varying the economy of scale component of the revenue distribution function, it is possible to develop a range of effects. The economy of scale determines how much more revenue a large firm generates compared to a small firm. As such, by varying the economy of scale from 1% to 100%, we generate the following ranges:

Table 4-3: Range of Economic Impact by varying Economy of Scale

	Effect Range for RDE ($ Millions)							
	Direct Effect		Indirect Effect		Induced Effect		Total Effect	
	Min	Max	Min	Max	Min	Max	Min	Max
CBD	$812.8	$883.9	$244.9	$260.9	$315.2	$345.6	$1,373.0	$1,490.3
Moraine	$683.8	$710.4	$166.5	$170.2	$232.0	$242.0	$1,082.3	$1,122.6
Fairfield Mall	$498.2	$538.8	$131.1	$142.4	$221.1	$238.2	$850.4	$919.4

Since each of these regions is composed of numerous industries, it is possible to develop a confidence interval by using Chebyshev's rule (Equation 4-1) for any distribution of revenue for each of the effects (direct, indirect and induced) (Figure 4-1), as well as for the total effect. (Figure 4-2) Chebyshev's rule allows the construction of confidence intervals of at least 89% for any distribution using the mean and standard deviation of the data with the following formula:

Equation 4-1

$$C.I._{89\%} = \bar{X} \pm 3(\sigma)$$

$\sigma =$ Standard Deviation

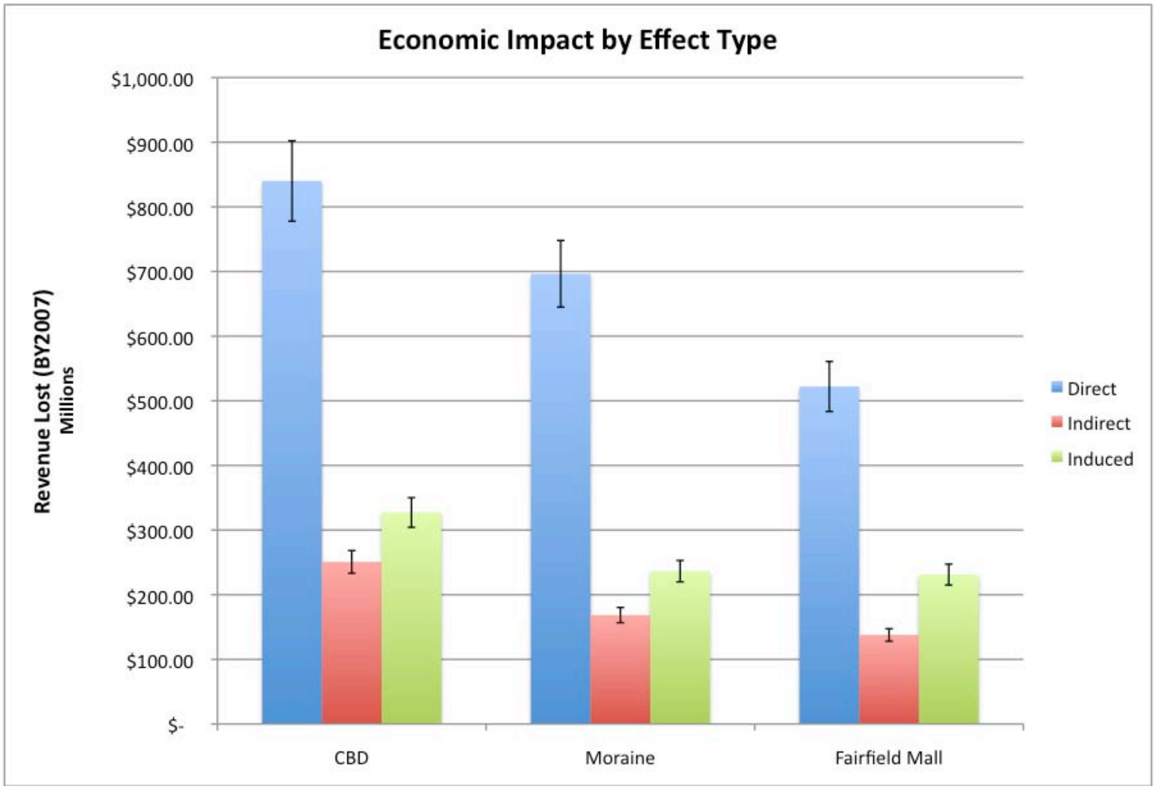

Figure 4-1: Confidence Interval of Economic Impact by Effect Type

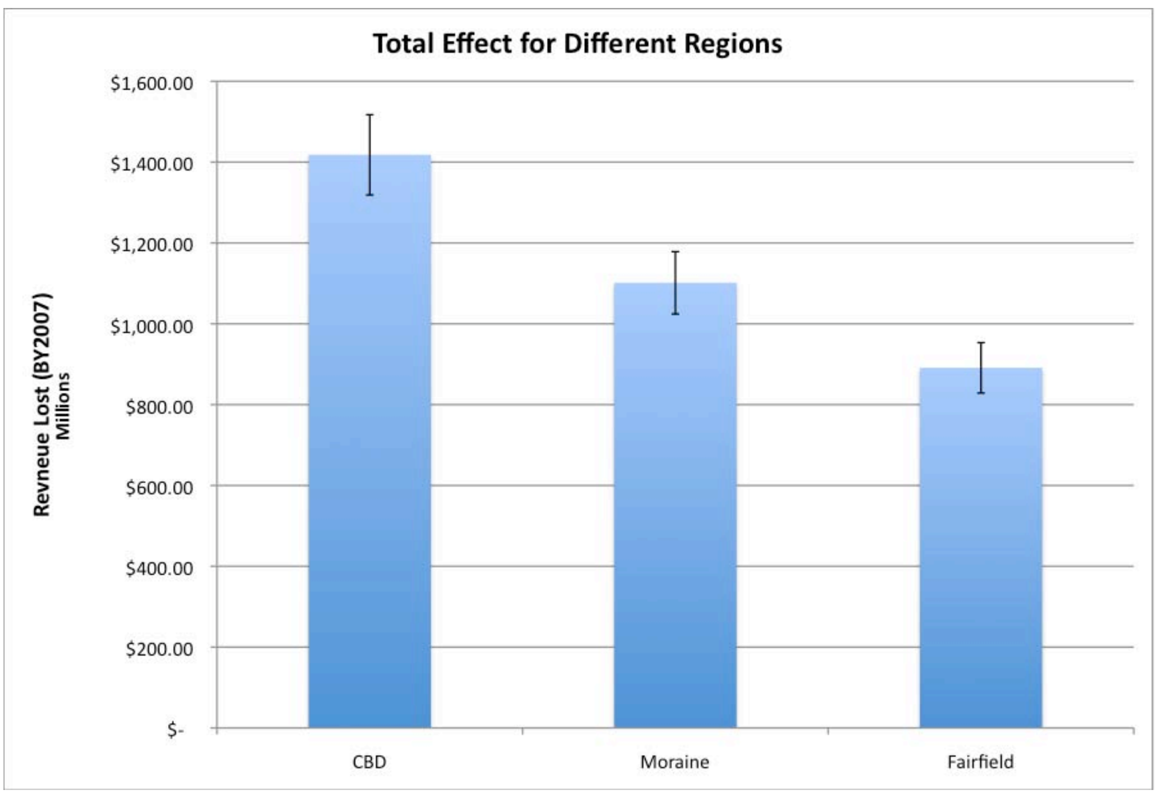

Figure 4-2: Confidence Interval of Total Economic Impact by Region

Central Business District

Within the CBD, we see the most variation, the majority of which comes from the direct effect. The induced and indirect effects are more contained and as such offset the variation seen within the CBD. Plotting the curve of the effect over the percentage of economy of scale, we can see the breadth of range contained within the CBD. (Figure 4-3)

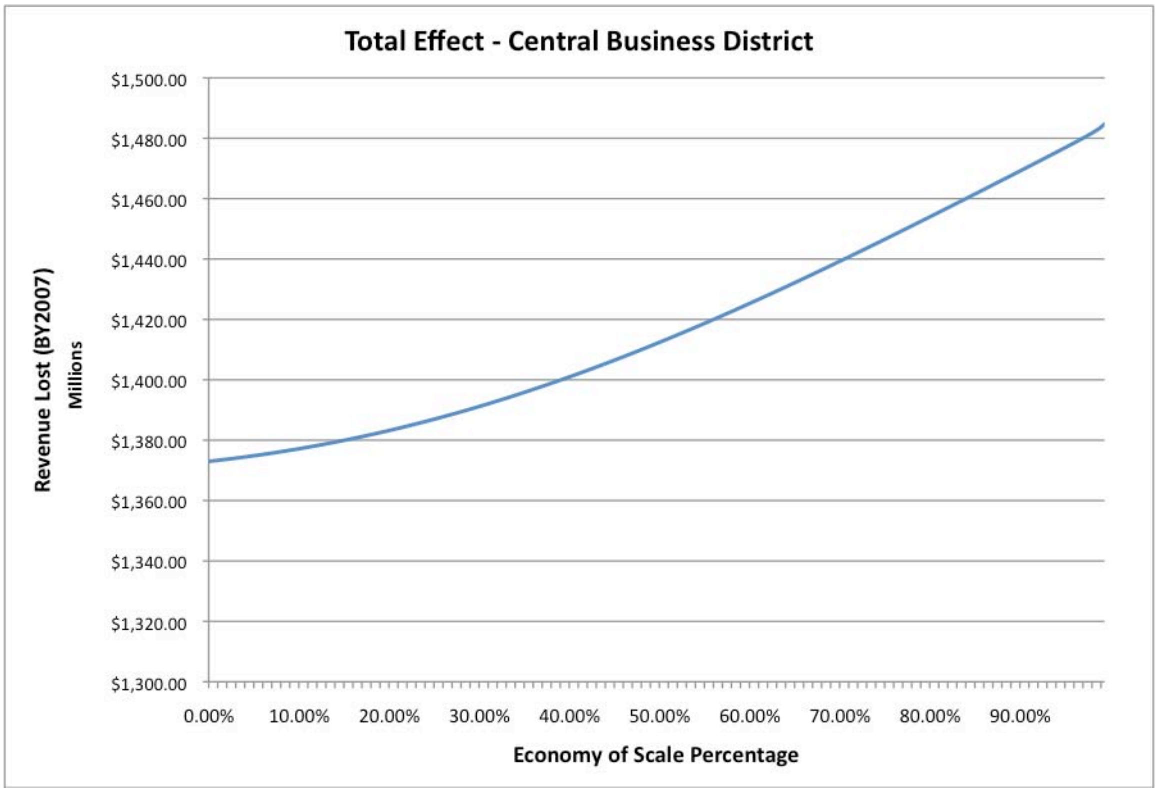

Figure 4-3: Total Effect in Central Business District with variations to Economy of Scale

This curve clearly illustrates the range of possible outcomes for the Central Business District as the economy of scale shifts between 1% and 100%. The depth of this variation occurs because the composition of the CBD is predominantly composed of firms that can either afford the high costs of operation (rent) within the downtown area or are firms who maintain a small commercial operation and can afford to remain in the CBD despite the high operating cost. As a result, the composition of the first group (firms which can afford the high cost) is typically corporate offices which are considered mid-size to large based on the number of employees. The composition of the second group (firms which are small enough to not incur high operating costs) is small businesses with few employees. Additionally, since these firms are in many varied industries, they can be considered competitors as opposed to complementary producers.

A complementary firm is one that produces a product to support or in conjunction with another related firm (i.e., automobile assembly plant and brake manufacturing plant), while competitors are vying for business against each other (i.e., four or five small accounting firms competing with one mid-sized corporate accounting firm). Although there are numerous industries within the CBD, there are enough firms collocated that competition is prevalent. Therefore, as the economy of scale is varied, the shifts are magnified because of the variety of different sized firms in competing industries within the CBD.

Moraine

Moraine is a major industrial center and contains the GM assembly plant. Although the curve (Figure 4-4) is of a similar shape as the CBD curve, the actual variation within Moraine is minimal when compared with the other two sites. This is a result of the narrow diversity and large size of the firms in the area. Moraine was built around the GM assembly plant. The area primarily consists of a small number of large firms in related industries (complementary producers), although there are some small firms within the area in unrelated business such as fast food restaurants, barber shops, gas stations etc, these firms are not competitors of the primary industry (the automotive industry) within the region. Rather, they are services dependent on the main industry. Therefore, as the economy of scale varies, the large related firms only experience a slight shift in revenue since they have no direct competitors within the region or MSA, resulting in less variation of revenue lost.

Additionally, the curve of the revenue line in Figure 4-4 is more linear in appearance than the CBD curve. This again can be attributed to the composition of industries within the Moraine region being complimentary instead of competitive as well as

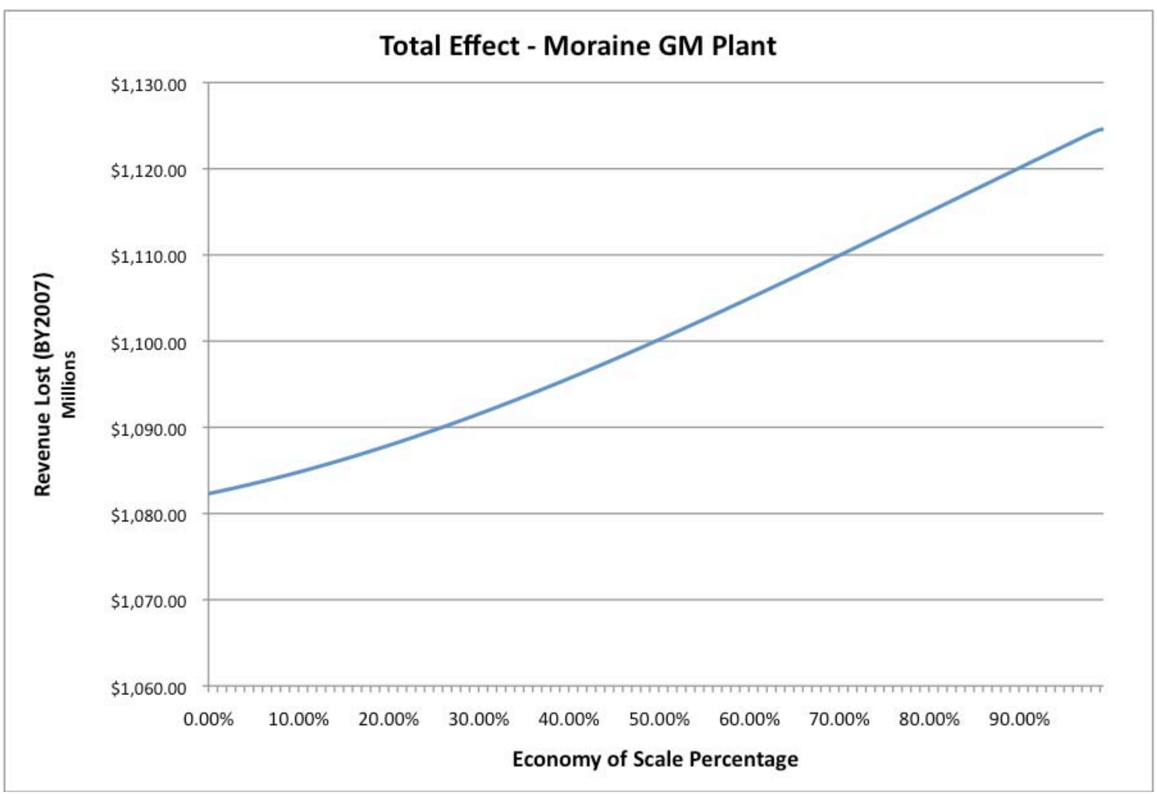

Figure 4-4: Total Effect in Industrial Region (Moraine) with variations to Economy of Scale

the lack of variety in size. There are a distinct number of small firms and a few very large firms but there are almost no firms within the mid-size range. This could possible contribute to the curves linear appearance while the economy of scale percentage remains large, but as the economy of scale is below 25%, the curve captures a more parabolic appearance.

Fairfield Mall

The Fairfield Mall is the least impacted of the three regions. The variation of this region is less than the CBD but greater than Moraine and is driven primarily by the direct effect. However, the indirect and induced effects should not be discounted as

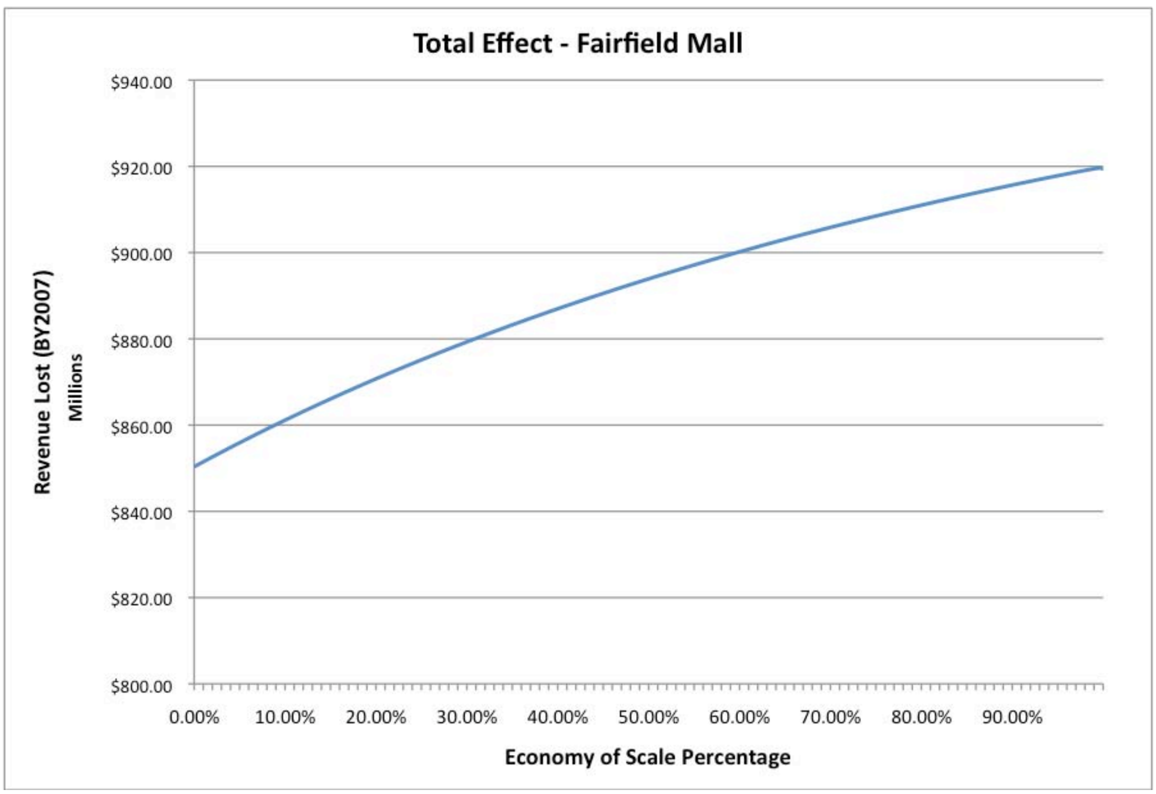

Figure 4-5: Total Effect in Retail Region (Fairfield Mall) with variations to Economy of Scale

they contribute significantly to the variation as well. In addition to having such variation, the Revenue Lost to Economy of Scale plot (Figure 4-5) is unique in its curvature. The curve is slightly convex, unlike the curves for the CBD or Moraine, indicating that there are diminishing revenue reductions for the Fairfield Mall as the economy of scale is increased.

Furthermore, the Fairfield Mall was the previous study site of a simulated RDE attack. (LeBrun, 2009) The results of that study found a total impact of $1.2 billion (BY2003) and 21,374 jobs impacted. Because the revenue of LeBrun's study is within the same frame of reference as the estimates from this research, it is a strong indication that the measure of $891M (BY2007) is a good estimate. While these results are still within the same scope as LeBrun's findings for the Fairfield Mall, they differ significantly. There are a number of factors that may have caused LeBrun's estimate to be over $300 million greater then the results of this study.

LeBrun built his estimates based on square footage of a retail center and the known relationship of revenue per square foot while I used data generated from the BLS at the MSA level and scaled down to the regional level. The three largest sectors in LeBrun's model (which accounted for almost 25% of the estimated revenue) had decreased their revenue significantly between 2003 and 2007. In addition to having the revenue decrease, the IMPLAN multipliers from the model had also shifted downward between 2003 and 2007 by almost 50% for those three sectors. The changes in the growth of the economy (the beginning of a recession) shifted the multipliers used in this study downward when compared to LeBrun's and this account for the difference between our results.

Seasonality Analysis

The results generated from the seasonality analysis conducted for each of the regions revealed some surprising results in regards to which month resulted in the greatest economic impact on the affected region as well as volatility of the seasonal effects for each region.

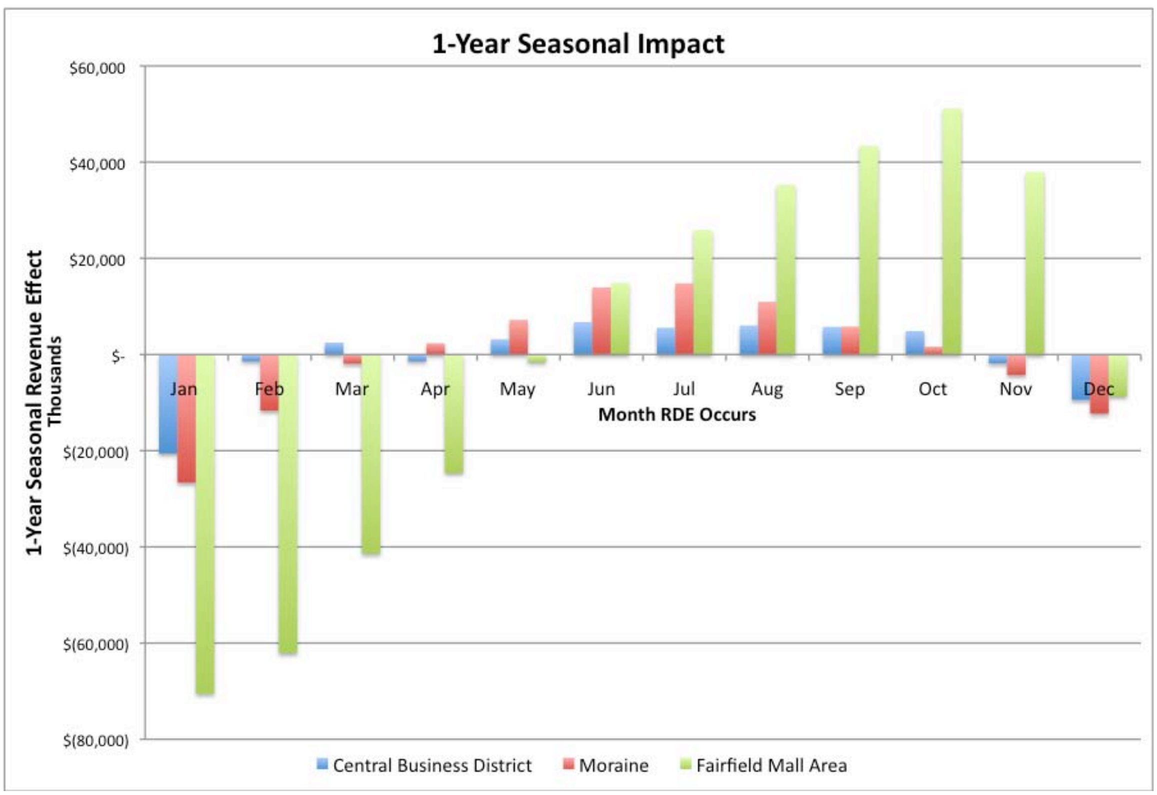

Figure 4-6: Seasonal Impact by Month of RDE

Central Business District

Over the 12-month period of data from 2007, it is possible to determine which month will cause the largest economic impact from an RDE. In order to easily quantify this, the cumulative seasonality effects on the revenue must first be isolated. Differencing the cumulative seasonality revenues from the cumulative monthly revenue, assuming no seasonality exists, provides us with a clear cut time series of the effect of seasonality (Figure 4-7)

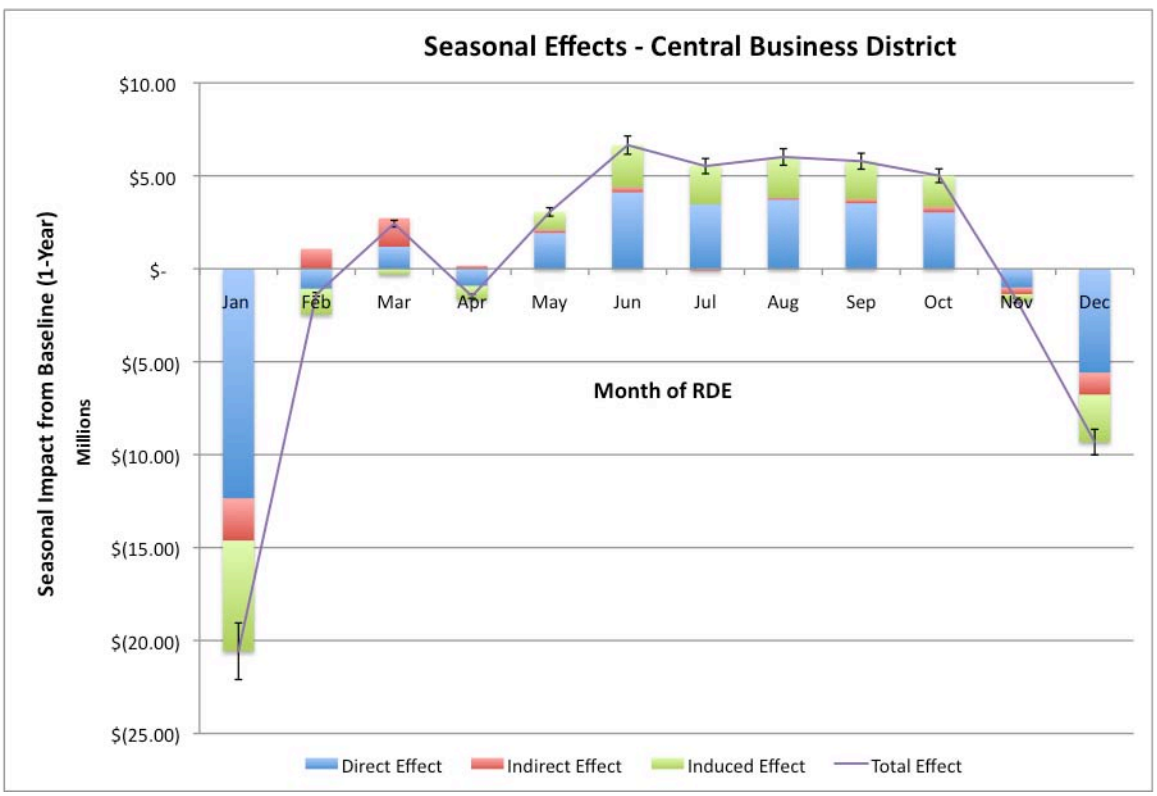

Figure 4-7: Season Effects of the RDE in the CBD – attack occurs in Month 1

By evaluating the area under the curve, we can determine the total net effect of when the RDE occurs compared to an event without considering seasonality. An original assumption was that the month of most impact would be October, November, or December, which is generally when retail businesses have the most sales. However, the results are quite unexpected: within the CBD, the summer months (June, July or August) result in the largest economic impact. Overall, an attack in June would result in and additional $6.7 million in economic losses above the cumulative (non-seasonal) average. Conversely, an attack in December would net $9.4 million below the cumulative average.

The variation is strictly considering seasonality; however, why does an RDE in the summer months produce results above the non-seasonal average? Summer is the time major construction projects are started throughout the United States ranging from simple home construction to larger undertakings such as infrastructure projects. Although there are a number of firms within the CBD related to construction and facilities maintenance, there are also a number of supporting industries collocated in the CBD as well such as accountants, attorneys, telecommunication specialists, and realtors. This keeps the seasonal income above the non-seasonal average through the summer and until the fall where the major revenue spike occurs. If the RDE occurred in the fall, the impact will be less. An RDD detonation in winter gives a below average result as the potential extra impact from the summer and fall will not be materialized.

However, this seasonality effect is not significant when compared to the magnitude of the effect as a whole. For the CBD, an additional $6.7 million loss would occur at the peak month. When compared to the $1.4 billion that will be impacted in the CBD, an additional $6.7 million will hardly be noticed and will get absorbed into the larger figure. However, seasonality is still a factor not just because of the added value, but also because of the heightened potential of when an attack might occur and must be considered as part of the analysis.

Moraine

Similarly to the CBD, the month of the largest economic impact of an RDE in the industrial center is July. (Figure 4-8) The worst month for an RDE in Moraine is July;

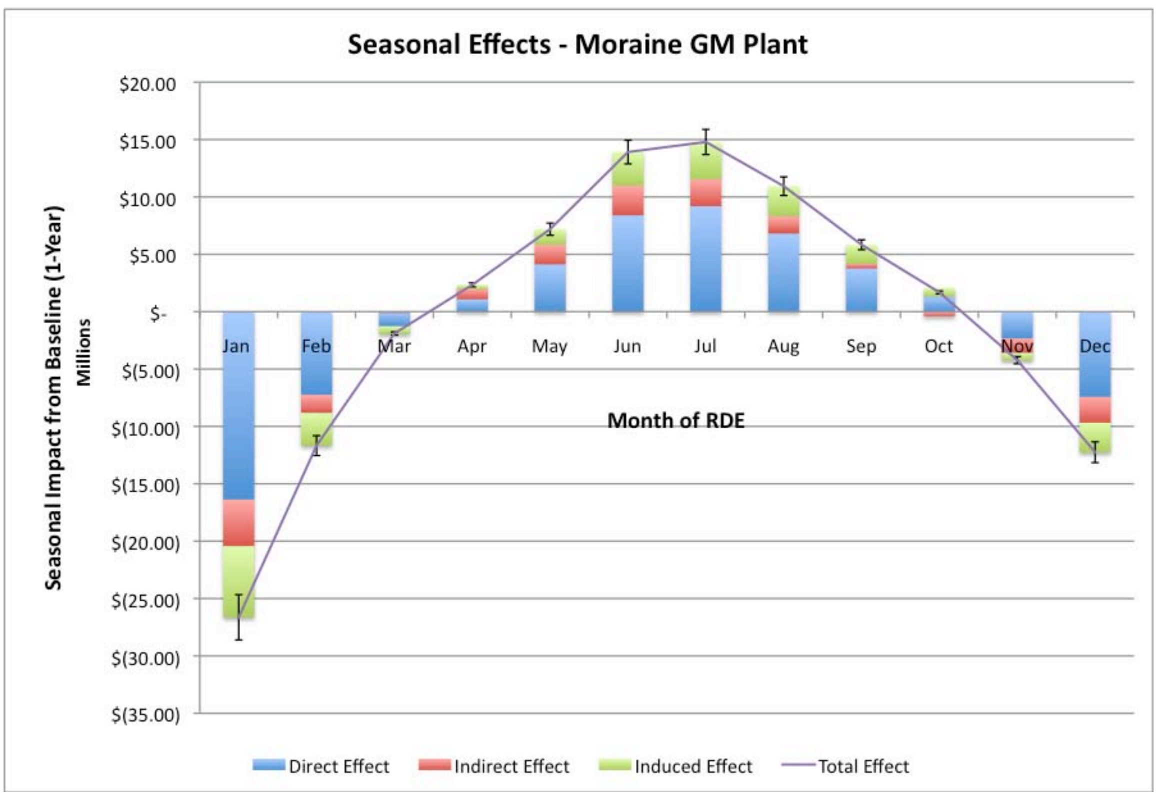

Figure 4-8: Season Effects of the RDE in Moraine (Industrial Area) – attack occurs in Month 1

the impact will be $14 million above the non-seasonal average.

The automotive industry, which is a significant portion of the industry base in Moraine, is seasonal. Historically, the automotive industry as a whole has always had two peaks, one in the spring (May and June) with a secondary peak in October and a trough in December. (Kuznets, 1975) However, these peaks are for the industry as a whole and are a composite of the production runs from the major automotive groups. Since industries in Moraine are focused around the GM automotive plant, it is critical to understand the GM production season. General Motors runs its peak production in October (producing 93,000 vehicles in October 2007) and has a trough in July (producing only 52,000 vehicles in July 2007). (General Motors Corporation, 2007). However, because a number of supporting industries are collocated with the GM plant, production in July is starting to increase in intensity, ensuring the month of July is above average. Once GM begins its peak production push in September through December, it is already too late for an RDE to cause an above average effect. An attack in July will produce a $14 million above average impact while an attack in December will result in an impact $12 million below average for the Moraine region.

Similar to the CBD, the total effect within Moraine is so large ($1.1 billion) that $14 million above the average impact would be very small. These seasonal effects are so insignificant that they fall within the range of confidence for each of the sites. However, it is important to note that despite their relatively small size, and all other factors being equal, the seasonal factor may be an indication of which months a terrorist will choose to attack and ultimately for us, which months security should be increased and vigilance heightened.

Fairfield Mall

Upon examination of the seasonality effect, it is apparent that the Fairfield Mall is again unique from the CBD or Moraine. (Figure 4-9) Unlike the CBD or Moraine, the

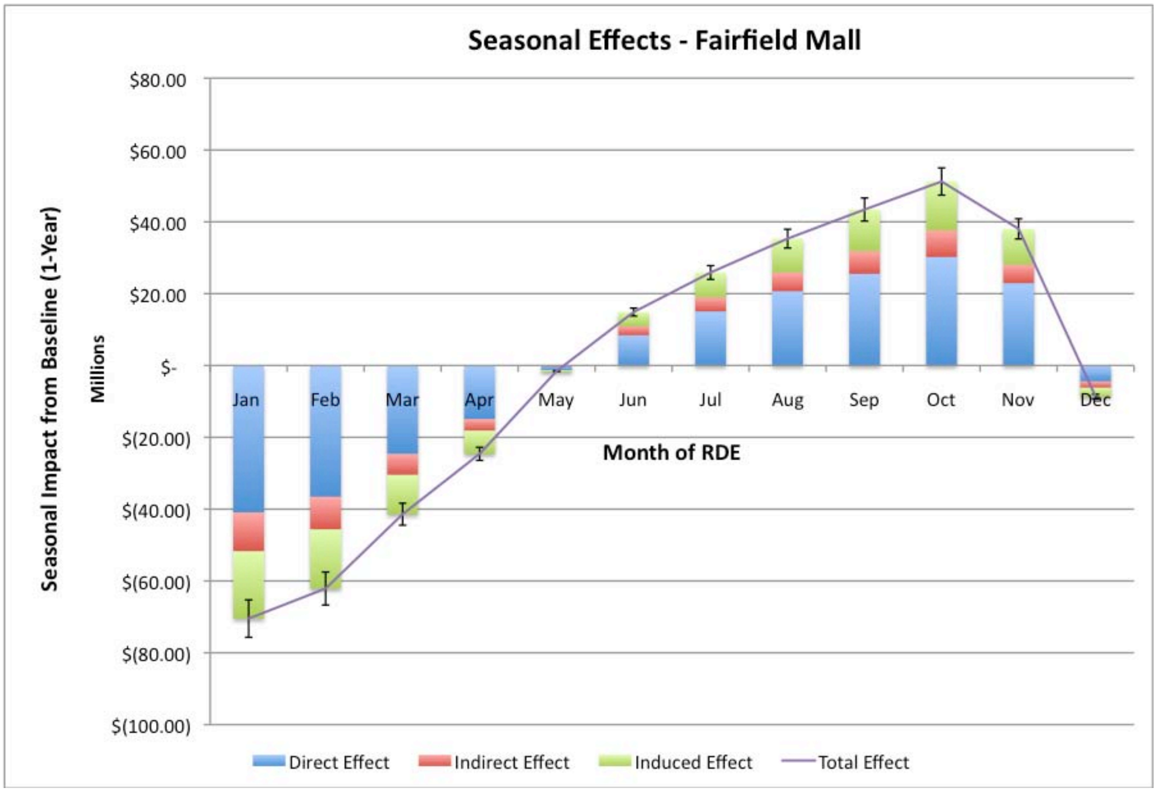

Figure 4-9: Season Effects of the RDE in the Fairfield Mall (Retail Area) – attack occurs in Month 1

Fairfield Mall appears to follow conventional thought on which month, if an RDE occurred, would result in the largest impact. An attack occurring in October would result in the largest the impact on the economy.

October is the start of the peak period of consumer purchases; most retail stores make the majority of their annual revenue in October, November and December. A detonation of an RDE within the Fairfield Mall area would easily disrupt those peak months. The retail sector appears to have a sharp increase in the fall months and a steady decrease throughout the rest of the year, unlike the CBD and Moraine, which held a gradual increase until a peak period followed by a gradual decrease.

An attack occurring in October will net an above average effect of $51 million while an attack in January, immediately after the peak season, will have effects $70 million below the non-seasonal average.

Relationship Between Number of Firms and Total Impact

There seems to be a relationship between the estimated economic impact of an RDE within an urban environment and the number of firms impacted by the area. (Table 4-4) Given the assumption that the only information known is restricted to the total annual revenue within the MSA, the total numbers of firms within the MSA, and the number of firms within the selected region for analysis, it is possible to estimate the impact.

Table 4-4: Estimation of Economic Impact by Number of Firms

		CBD (Millions)	Moraine (Millions)	Fairfield Mall (Millions)
Location Factor		1.5	1.666666	1.33333
MSA Average Revenue/Firm ($1,000)	Number of Firms in Region	860	580	575
$ 681	Direct Effect	$878.8	$658.5	$522.3
$ 204	Indirect Effect	$263.6	$197.6	$156.7
$ 272	Induced Effect	$351.5	$263.4	$208.9
	Total Effect	**$1,493.9**	**$1,119.5**	**$887.9**

In order to develop a rough approximation of the total impact of an area, the first step needed is finding the average revenue per firm for the MSA using the following formula:

Equation 4-2

$$\text{Average Revenue per Firm} = \frac{\text{Total Revenue in MSA}}{\text{Total Number of Firms in MSA}}$$

Using this average from Equation 4-2, we can begin to estimate the direct effects of a RDE by multiplying Equation 4-2 by the number of firms in the study site and factoring in the location factor for the site in question.

Equation 4-3

$$\text{Direct Effect} = (\text{AR/F}) \times (\text{No. of Firms}) \times (\text{LF})$$

The Average Revenue per Firm (AR/F) is the result of Equation 4-2; the number of firms within the study region is obtained from public records. The Location Factor (LF) is determined by the percentage of revenue conducted within the study site when compared to the average revenue of other similar regions. For example, in this study, the CBD produced 50% more revenue than the average business district and a factor of 1.5 was applied as the location factor.

Once the direct effect is determined, calculating the indirect and induced effects require estimating an Effect Factor (EF) of the average revenue per firm (Equation 4-2).

In the case of Dayton, Ohio, I estimated that the indirect effect was approximately 30% of the average revenue per firm and the induced effects were approximately 40%. These percentages were derived by taking a weighted average of the IMPLAN multipliers (indirect and induced), weighted by the IMPLAN sectors within the MSA, which produced an average of .3 and .4 respectively. Once applied, Equation 4-2 can be used to calculate the indirect and induced effects. A generalized version of Equation 4-2 can be found below: (Equation 4-4)

Equation 4-4

$$\text{Effect} = (\text{AR/F}) \times (\text{No. of Firms}) \times (\text{LF}) \times (\text{EF})$$
$$\text{Effect} = \text{Direct Effect} \times (\text{EF})$$

The total effect of an RDE attack can then be estimated by the summation of the direct, indirect and induced effects.

Implications

The numbers generated by following these formulas are strictly an approximation and should not be used in lieu of the methodology outlined in chapter 3 to generate an estimate. Rather, this method highlights a previously unknown relationship between the number of firms within an industry and the total effects of the study site. This relationship highlights that for an urban center with limited resources, protecting the site or sites of highly congested areas such as the CBD will provide the best amount of protection for dollar spent. Additionally, this quick method may validate the results generated from the more accurate and complex method to ensure the estimates are correct. This unexpected relationship is inherently valuable as a tool to validate estimates generated from the method developed by this study.

Examining the Central Business District

The CBD is, without any doubt, the area that will be the most effected by an RDE. This is not an unexpected result as is does follow convention that the CBD which is the heart of the MSA will contain the largest amount of revenue in any given area and by disrupting the CBD, the greatest impact would occur. The CBD contains more firms within the same area than anywhere else within the MSA. It is considered the nerve center of any city and contains the primary commercial center. In the event of an RDE, the total annual economic impact for Dayton, OH will be approximately $1.4 billion dollars, affecting 18,000 people directly and 113,000 from indirect and induced effects. The total effect on annual revenue is disaggregated into direct, indirect and induced effects. (Table 4-5)

Table 4-5: Direct, Indirect, Induced and Total Effects for CBD

($ Millions)	Direct Effect	Indirect Effect	Induced Effect	Total Effect
Mean	$839.7	$250.7	$327.1	$1,417.5
Confidence Interval CI_{89}	±$61.0	±$13.8	±$26.6	±$101.3

In addition to being the most impacted area for an RDE, the CBD contains numerous public buildings such as courthouses, libraries and city hall. The CBD is also an area of high vehicular and pedestrian traffic and contains numerous public transportation nodes allowing (low-income) individuals without a personal vehicle access to and from city suburbs. An impact to this area will not be only economically devastating, but will devastate the entirety of the MSA; an attack in the CBD will disrupt the citywide traffic flow, hamper coordination of public services (fire, police, medical) and restrict the movements of the MSA residents as well as goods and services throughout the city.

The effects measured in this study are based strictly on revenue in order to facilitate a comparison between regions. It is difficult to quantify the benefits public government has provided and as such it was excluded from the analysis. It should be recognized that an RDE within the CBD will be much more devastating than the estimated impact because of the geographic structure of a city around the CBD.

V. Discussion and Conclusion

Many opportunities are available for future researchers to build upon this study as well as to improve it. The following chapter discusses limitations, recommendations, and areas for further research. However, before we can consider the limits of this study and future areas of research, it is critical to understand the methods used and highlight the critical results obtained from my analysis.

Methods Used

Modeling the economic impact of an RDE required critical information. This study used datasets from the BLS to generate the number of firms and revenue of those firms within three distinct areas of the MSA – the Central Business District (Commercial Center), the Moraine GM Plant (Industrial Center) and the Fairfield Mall (Retail Center). In order to effectively analyze each area, the total revenue effects were calculated via IMPLAN multipliers. IMPLAN is analysis software package that generates a series of multipliers for each sector of industries based on their interrelationships with other industries and within the MSA, known as Input-Output Modeling. Multipliers are a numeric way of describing the impact of a change to the revenue or employment levels. The multipliers allow calculation of the direct, indirect, and induced effects of a change to the revenue or employment level. In addition, the summation of these three effects shows the total impact to the MSA based on a change in revenue or employment. Prior studies have only been able to calculate the direct effect and as such have not accounted for a substantial effect of the economic impact

In order for this model to be usable as a tool for decision-makers, I had to make certain assumptions. I assumed the size and type of the contamination area as well as linear economies of scale. I did not consider location factors with regard to computing the model results although location factors were needed to develop the estimate based strictly on firm density within an area. These assumptions will not impact the methodology nor change the overall outcome of this study.

Critical Results and Discussion

Following a systematic approach, I was able to develop some very interesting results. This process is repeatable and the method can be generalized to other MSAs. Ultimately, the effects of any RDE of the size described in NPS Scenario 11 will be devastating.

Area of Greatest Impact

The most substantial impact will occur if an RDD is detonated within the Central Business District (CBD). Such an attack within the CBD will result in a total effect of $1.4 billion (BY2007) over a 1-year period. The seasonality factor determines the time of year an attack will have the most impact. The summer months of June, July, and August produce the greatest seasonal effects, while an attack in December or

January would reduce the impact below the calculated non-seasonal average. Although the CBD contains the largest impact to the MSA, attacks in Moraine or Fairfield Mall should not be discounted, as they will have a 1-year total effect of $1.1 billion and $900 million respectively.

Relationships in Direct, Indirect, and Induced Effects

The ratios of direct to indirect to induced effects remained fairly consistent at all three sites within this study at 60%, 15%, and 25%, respectively. Interestingly, out of the total effect, 40% is not immediately realized (indirect and induced effects). This is because indirect and induced effects are time-lagging effects. These effects will be realized months after the RDE. Not considering the indirect and induced effects often results in a broad underestimation of the effects at all levels of government. In the case of an RDD detonation, the impacted area would require the assistance of Federal government aid through the Federal Emergency Management Agency (FEMA). This type of analysis will help FEMA determine the level of assistance required and will improve future cost estimates. From previous studies, the process used to estimate future-year funding to be appropriated by Congress is often underestimated.

FEMA uses the 5-year annual average level of obligations for past disasters, adjusted for inflation, as its estimate of the total cost of disasters anticipated to occur during the current fiscal year. The costs used to develop the five-year average are taken from the required cost-estimate conducted within 90 days after the declaration of disaster. This cost estimate is strictly a measure of the direct effects, as the indirect and induced effects are lagging and their economic impacts are not yet evident and not considered in the estimation of future financial needs.

To estimate when during the year the disasters will occur, FEMA simply allows the five-year annual average to decline at a constant rate (8 percent) each month during the fiscal year, with no model for seasonality. As a result, the Federal government is not only measuring the direct effects of a disaster (which only accounts for 60% of the total economic impact), but they are regularly underestimating the cost of disaster events due to seasonality factors. This underestimation by FEMA results in an annually underestimated congressional appropriation. As a final result, an RDE attack will not only devastate the region attacked, but will also require additional unplanned appropriations, adding to our ever-growing national debt.

"Ball Park" Estimates

During this analysis there was discovered a relationship between the number of firms in an area and the magnitude of the economic impact. This means that there is an inherent process available to validate the estimates generated via the methodology outlined in this research.

It is imperative that civic leaders at all levels use this information to preemptively protect the densest areas of our cities. Underestimating our adversaries is our greatest weakness as a nation and is exploited without hesitation.

Limitations

Input-Output Models

While IMPLAN does a good job at estimating economic impacts to output and employment, the software does have limitations. The economy is a dynamic and complex entity with economic data constantly changing. However, in order to generate I-O Models, IMPLAN utilizes historic economic data to build its models and multipliers (2007 economic data). Additionally, IMPLAN is unable to account for costs resulting from immediate actions such as cleanup or remediation efforts. Additionally, the model does not account for the impact to residential property values nor the residual costs associated with psychological factors or the potential exodus of people from the impacted area and its impact on the economy. These costs are expected to be a substantial burden valued at "hundreds of millions of dollars per site." (US Department of Homeland Security, 2006)

Economies of Scale

Actual economies of scale are generally not linear; rather, are some form of geometric or exponential growth curve. This study used a linear approximation for the economies of scale in order to confirm a difference between a method that accounts for economies of scale and one that does not. Future analysis using this study's methods must include a factor for economies of scale. Any estimate, which holds economies of scale constant, will not accurately predict the economic impact of a district within an MSA. Within the context of this study, it is sufficient in its ability to reflect the revenue distribution between small firms and large firms proportionally via a linear approximation. This linear approximation allowed for a more accurate model, while the accuracy lost by not applying exponential curves to economies of scale is not substantial enough to warrant the added complication of more complex modeling.

Location Factors

Different sites of similar type will have varying revenues based on both actual revenue generated and factors associated with the location of the site within the MSA. However by selecting the largest site of each type district, this study has provided an upper bound for RDE analysis.

Recommendations

As illustrated within this research, the economic fallout resulting from an RDE has the potential to be quite costly. Therefore, officials and planners at all levels of government must assume a proactive posture when dealing with the threat. The methodology outlined within this research serves as a tool that planners and officials in any location can use in order to facilitate the planning and decision-making process. Through informed decision making and strategic planning, leaders can make effective decisions as to what preventive measures should be in place or how resources should be optimally allocated among competing options in the event of a RDE occurring within their area.

An economic impact analysis allows key stakeholders to attain a better understanding of the possible magnitudes and ranges of possible economic impacts resulting from a RDE. As a result, leaders can better determine where to allocate limited resources to prevent and deter an RDE attack. If recovery and resiliency to an RDE is to be maximized, effective and efficient planning is critical.

Future Research

This study focused solely on quantifying commercial economic impacts resulting from a RDE. Other economic parameters, such as cleanup and remediation costs, or residential considerations were not taken into account. Realistically, the overall economic impacts would have been higher if these additional parameters were included within the economic impact calculations.

Additionally, repeated iterations of the methodology in various MSAs will provide new insights into the effects and interactions between distinct intra-city regions and provide a further validation of this research.

This study was unable to account for local government revenue lost due to the impact. It is possible to measure these effects with business tax multipliers. By including these effects, a better picture would be presented as to the impact total to government income.

Conclusion

This research examined the economic impacts of a RDE on the three distinct regions of a mid-sized urban economy. The methodology outlined within this composition is unique in that it aids in the RDE response effort by providing government planners, officials, and key stakeholders with an economic impact assessment method. This process can be used by any city throughout the United States to determine the effects (direct, indirect, and induced) that an RDE would have on the economy. Furthermore, this study identified a relationship between the effect of the impact and the density of firms surrounding the RDE. This relationship is important because it helps facilitate planning as well as effective and efficient decision making in response to the threat. As a result, preventive measures can be in place, resources efficiently allocated, and recovery and resiliency maximized before the RDE occurs. This is the true value of this research.

Works Cited

Blair, J. P., & Carroll, M. C. (2009). *Local Economic Development: Analysis, Practices, and Globalization* (2nd Edition ed.). Sage Publications.

Boyle, A. (2002 10-June). Dirty bomb's biggest hazard: panic Experts say radiation would play on public fears. *MSNBC* .

Carafano, J. J., & Spencer, J. (2004). Dealing with Dirty Bombs: Plain Facts, Practical Solutions. *Backgrounder , 1723* (27).

Center for Non Proliferation Studies. (2004). *Center for Non Proliferation Studies*. (M. I. Studies, Producer) From Radiological Terrorism Tutorial Ch2, 4: http://www.nti.org/h_learnmore/radtutorial/index.html

Cheng, S., Stough, R. R., & Kocornik-Mina, A. (2006). Estimating the Economic Consequences of Terrorist Disruptions in the National Capital Region: An Application of Input-Output Analysis. *Journal of Homeland Security and Emergency Management , 3* (3).

Clark, J. (1984). Estimation of Economies of Scale in Banking Using a Generalized Functional Form. *Journal of Money, Credit, and Banking , 16* (1).

Club de Madrid. (2005). Addressing the Causes of Terrorism: The Club de Madrid Series on Democracy and Terrorism. *The International Summet on Democracy, Terrorism, and Security. I.* Madrid.

Council on Foreign Relations. (2006 19-October). *Backgrounder: Dirty Bombs*. Retrieved 2009 йил 23-July from http://www.cfr.org/publication/9548/

Ferguson, C. D., Kazi, T., & Perera, J. (2003). *Commercial Radioactive Sources: Surveying the Security Risks.* Occasional Paper 11, Monterey Institute of International Studies, Center for Nonproliferation Studies, Monteray, CA.

Flynn, C. B. (1979). *Three Mile Island telephone survey: preliminary report on procedures and findings.* Mountain West Research, Inc.

Frost, R. M. (2005). *Nuclear Terrorism After 9/11.* Routledge for The International Institute for Strategic Studies.

Gardner, F. (2003 31-January). Al-Qaeda 'was making a dirty bomb'. *BBC News World Edition* .

General Motors Corporation. (2007). *US Passenger Vehicle Production.* Monthly.

Google, Inc. (n.d.). *Google Maps*. Retrieved 2009 March from Google Maps: maps.google.com

Gordon, P., Moore, J. I., Richardson, H., & Pan, Q. (1 May 2005). *The Economic Impact of a Terrorist Attack on the Twin Ports of Los Angeles-Long Beach.* University of Southern California, Center for Risk and Economic Analysis of Terrorist Events. University of Southern California.

Graham, B., & Talent, J. (2008). *World at Risk: The Report of the Commission on the Prevention of WMD Proliferation and Terrorism.* Commission on the Prevention of WMD Proliferation and Terrorism. Vintage Books.

Grotto, A. (2005 July). Defusing the Threat of Radiological Weapons: Integrting Prevention and Detection and Response. *Center for American Progress* .

International Atomic Energy Agency. (2006). *Chernobyl's Legacy: Health, Environmental, and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine.* The Chernobyl Forum 2003-2005, IAEA Division of Public Information. Austria: IAEA.

International Atomic Energy Agency. (September 1988). *The Radiological Accident in Goiania.* Vienna.

Kuznets, S. S. (1975). *Seasonal Variation in Industry and Trade.* Ayer Company Publisher.

Lamb, R. P. (1995). An Exposure Based Analysis of Property & Casualty Insurer Stock Values Around Hurricane Andrew. *Journal of Risk and Insurance , 62* (1), 111-123.

LeBrun, M. T. (2009). *The Economic Impact of a Radiological Dispersal Event (RDE).* Air Force Institute of Technology, Systems and Engineering Management. Air Education and Training Command.

Makinen, G. (2002). *The Economic Effects of 9/11: A Retrospective Assessment.* Congressional Research Service. United States Congress.

McIntosh, C. (1997). Education's Importance in the Region. *The Regional Economy* .

Minnesota IMPLAN Group. (2009 йил 12-September). *IMPLAN.com Economic Impact Modeling Solutions*. Retrieved 2009 йил 12-September from www.IMPLAN.com

Monterey Institute of International Studies Center for Nonproliferation Studies. (2004). *Radiologial Terrorism.* Nuclear Threat Initiative. Monterey Institute of International Studies.

Natural Resources Conservation Service. (2009 21-August). *IMPLAN Model*. Retrieved 2009 йил 12-September from United States Department of Agriculture: http://www.economics.nrcs.usda.gov/technical/implan/implanmodel.html

Okuyama, Y., Hewings, G. J., Kim, T. J., Boyce, D. E., Ham, H., & Jungyul, S. (1999). Economic Impact of an Earthquake in the New Madrid Siesmic Zone: A Multiregional Analysis. *5th US Conference on Lifeline Earthquake Engineering.* Seattle, WA: U.S. Geological Society.

Rose, A., Oladosu, G., & Liao, S.-Y. (1997). Business Interuption Impacts of a Terrorist Attack on the Electric Power System of Los Angeles: Customer Resilience to a Total Blackout. *Risk Analysis , 27* (3).

Rosoff, H., & Winterfeldt, D. v. (2007). A Risk and Economic Analysis of Dirty Bomb Attacks on the Ports of Los Angeles and Long Beach. *Risk Analysis , 27* (3).

Sohier, A., & Hardeman, F. (2006). Radiological Dispersion Devices: are we prepared? *Journal of Environmental Radioactivity* , 171-181.

United States Department of Labor. (2010 1-January). *Bureau of Labor Statistics*. Retrieved 2009 йил 1-June from BLS.gov: http://www.bls.gov/data

United States General Accountability Office (GAO). (2008). *Disaster Cost Estimates: FEMA Can Improve Its Learning from Past Experiences and Management of Disaster-Related Resources.* Report to Congressional Committee.

United States General Accountability Office. (2000). *Disaster Relief Fund: FEMA's Estimates of Funding Requirements Can Be Improved.* United States General Accountability Office (GAO). United States Senate.

US Census Bureau. (2010 16-February). *2007 Economic Census*. Retrieved 2009 йил 1-June from Census Bureau: http://www.census.gov/econ/census07/

US Census Bureau. (2010 1-Januray). *American Fact Finder*. Retrieved 2009 йил 1-June from US Census Bureau: http://factfinder.census.gov/home/saff/main.html?_lang=en

US Department of Homeland Security. (2006). *National Disaster Planning Scenarios.* US Department of Homeland Security.

Walker, S. J. (2004). *Three Mile Island: A Nuclear Crisis in Historical Perspective.* Berkeley: University of California Press.

Warwick, M. (2001). Psychological Effects of Weapons of Mass Destruction. *The Beacon: National Domestic Preparedness Office Newsletter* (3), 1-4.

William C. Thompson, J. (2002). *One Year Later: The Fiscal Impact of 9/11 on New York City.* City of New York, Comptroller. New York: City of New York.

REPORT DOCUMENTATION PAGE				*Form Approved* *OMB No. 074-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to an penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
25-03-2010	Master's Thesis	August 2009 – March 2010

4. TITLE AND SUBTITLE

Method Of Measuring The Economic Impact Of A Radiological Dispersal Event Within An Urban Environment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Munfakh, Antoine N., Captain, USAF

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT-GFA-ENV-10-M03

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Ferguson, Marcus G., Major, USAF
711th Human Performance Wing, Biosciences Division, Counterproliferation Branch
2711 K Street, Building 434
WPAFB, OH 45433
DSN: 674-4652

10. SPONSOR/MONITOR'S ACRONYM(S)

711 HPW/RHPC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

A RDE is the result of a RDD or a dirty bomb. An RDD is a low-yield conventional weapon surrounded by radiological material such as Cesium-137 and is an affordable, feasible, and economically devastating option for terrorist groups.

The purpose of this research is to develop a generalized methodology that can assess economic impacts resulting from an RDE, occurring in any location and across any industry. Currently there is no universal approach for measuring the economic impacts on businesses. This research will provide government planners, officials, and key stakeholders with an economic assessment tool which can be used to quantify the impacts arising from a RDE.

As part of the methodology, this thesis used an I-O Model to evaluate the economic impacts of an RDE at three districts within a proposed study site. The methodology can be generalized to other regions or cities. The study showed that the direct, indirect, and induced costs remained consistent independent of the district at approximately 60%, 15%, and 25% respectively. The significance of such a finding is that previous attempts to quantify the impact only measured the direct effects and thus did not capture approximately 40% of the total costs resulting in gross underestimates.

15. SUBJECT TERMS

Economic Impact, dirty bomb, radiological dispersal event, input-output model, assessment tool

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Lt Col David A. Smith (AFIT/ENV)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	U	U	UU	86	937-255-3636 ext. 4711

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

	Form Approved *OMB No. 074-0188*